Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

1190 Issued September 27, 1909.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 217.

A. C. TRUE, Director.

DRAINAGE OF IRRIGATED LANDS IN THE SAN JOAQUIN VALLEY, CALIFORNIA.

BY

SAMUEL FORTIER AND VICTOR M. CONE.

[The work on which this report is based was done under a co-operative agreement between the Office of Experiment Stations of the U. S. Department of Agriculture and the State of California.]

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

OFFICE OF EXPERIMENT STATIONS.

A. C. True, Director.
E. W. Allen, Assistant Director.

IRRIGATION INVESTIGATIONS.

Samuel Fortier, Chief.

R. P. Teele, Editorial Assistant and Acting Chief in absence of the Chief.

IRRIGATION ENGINEERS AND IRRIGATION MANAGERS.

A. P. Stover, Irrigation Engineer, in charge of work in Oregon.

C. E. Tait, Irrigation Engineer, in charge of work in Imperial Valley and Arizona.

F. W. Roeding, Irrigation Manager, in charge of work in California.

S. O. Jayne, Irrigation Manager, in charge of work in Washington.

W. W. McLaughlin, Irrigation Engineer, in charge of work in Utah.

P. E. Fuller, Irrigation Engineer, in charge of power investigations.

O. W. Bryant, Irrigation Manager, in charge of work in Colorado and Wyoming.

W. L. Rockwell, Irrigation Manager, in charge of work in Texas.

D. H. Bark, Irrigation Engineer, in charge of work in Idaho.

Milo B. Williams, Irrigation Engineer, in charge of work in humid sections.

F. L. Bixby, Office Engineer.

V. M. Cone, Irrigation Engineer.

C. G. Haskell, Irrigation Engineer.

COLLABORATORS.

O. V. P. Stout, University of Nebraska, in charge of work in Nebraska.

Burton P. Fleming, New Mexico Agricultural College, in charge of work in New Mexico.

Gordon H. True, University of Nevada, in charge of work in Nevada.

Elias Nelson, Idaho Agricultural College, in charge of Caldwell farm, Idaho.

W. B. Gregory, Tulane University of Louisiana, in charge of rice irrigation in Louisiana and Texas.

IRRIGATION FARMERS.

John H. Gordon, R. G. Hemphill, W. H. Lauck, R. E. Mahoney, and John Krall, Jr.

[Bull. 217]

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., July 1, 1909.

Sir: I have the honor to transmit herewith the report of experiments in draining lands in the San Joaquin Valley, California, which had been injured by the rise of ground water and the accumulation of alkali. These experiments were carried on by Doctor Fortier and Mr. Cone, under a cooperative agreement between this Department and the State of California, each party bearing one-half of the expense.

In almost every irrigated section large areas of the lower lands have been ruined by the rise of the ground water and an accumulation of alkali, and the usual course has been to abandon the injured lands and transfer the water used on them to other lands. Often this means the abandoning of costly improvements, the building of new ditches and new structures, and the planting of new fruit trees and vines. These experiments show that drainage, which will hold the ground water below the roots of trees and vines, will prevent the injury of orchards and vineyards, and will quickly restore lands already injured at a cost much below that of reclaiming new lands and providing new equipment. While the experiments were confined to one region, the methods employed and the results obtained will apply to other sections having similar conditions. It is therefore recommended that this material be published as a bulletin of this Office.

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

Page.

Introduction 7

Drainage in Fresno County 9

- A view of the affected district 9
- Necessity for drainage 10
- The problem confronting the farmer 11
- Efforts to better conditions 12
- Selection of typical tracts for experiments 14
- The ground water 15
- General plan of experiments 19
- Details of constructing the tile-drainage systems 22
  - Laying tile in hardpan 24
  - Blasting hardpan 25
- Removal of alkali 27
- Cleaning tile 30
- Cost of tile work at Fresno 31
- Necessity for continuous operation of drainage plants during high water table 32
- The amount of water pumped and the effect on the ground-water level 34
- Extent of the influence of drains on the level of water table in adjacent lands 35
- Analysis of drainage water 36
- Analyses of soils on experiment tracts 36
- Percentage of open space in soils occupied by drainage water 39
- The capacity of a drainage system 40
- Practical observations made 41
- Results obtained in the drainage experiments at Fresno 42
- A drainage system outlined 44

Drainage in the Modesto and Turlock districts 46

- General description 46
- Pumping experiments 50
- Open-ditch drainage experiments 51
  - Experiment in the Turlock district 52
  - Experiment in the Modesto district 55

Summary 57

ILLUSTRATIONS.

PLATES.

Page.
Plate I. Map of Fresno district, showing irrigation canals 15
II. Map of Modesto and Turlock irrigation districts, showing location of irrigation canals and drains 52

TEXT FIGURES.

Fig. 1. Diagram showing ground-water levels, 1904–1908 15
2. Soil auger 16
3. Plat of Baker tract, showing tile lines 20
4. Plat of Dore tract, showing tile lines 21
5. Sand box in tile line 23
6. View showing spotted growth of Egyptian corn, due to blasting 26
7. Dore tract during flooding, showing character of levees 28
8. Sketch showing concentration of alkali on high ground 39
9. Skid dredge operating on Modesto and Turlock canals 53

DRAINAGE OF IRRIGATED LANDS IN THE SAN JOAQUIN VALLEY, CALIFORNIA.

INTRODUCTION.

The San Joaquin Valley occupies more than three-fifths of the great central valley of California. Extending from the Tehachapi Mountains on the south to Suisun Bay on the north, it includes in its great expanse of comparatively level land a large part of the irrigable area of the State. The floor of this valley, with its foothill and mountain watersheds, is nearly equal in extent to the State of Indiana. The run-off from this basin reaches the axis of the valley through a number of nearly parallel stream channels from the Sierras and thence it is conveyed by the San Joaquin River to Suisun Bay, from whence it flows through the Golden Gate to the ocean.

For years after the discovery of gold in California the valley remained virgin soil. Bunch grass carpeted the swamp area of the trough of the valley; wild oats grew on the higher land near the foothills; but the large expanse of rich land between these borders supported only a scant growth of grass and alfilaria during the rainy season. During the greater part of the year the valley was too dry, barren, and devoid of green vegetation to attract even the herds of wild horses and cattle from the slopes of the Sierras. In the course of time, however, as the valley became settled, the grain raisers took advantage of the winter rainfall to raise profitable crops of wheat.

Irrigation development in this part of California dates back to the early seventies, when the people of Fresno County began to use a part of the water of Kings River for the production of fruits and grapes. Prior to 1875 a number of small canals were built to supply water to lands near Bakersfield, and in that year the Calloway Canal, belonging to the Kern River Land and Canal Company, was built to convey 500 cubic feet per second to lands on the north side of Kern River. The Modesto and Turlock irrigation districts, although organized in 1887, used little water until 1902. The practice of irrigation has gradually extended from these centers until at the present time there is probably more than 1,000,000 acres irrigated. The volume of water required for this area exhausts the flow of the stream after the spring floods have subsided, and in all probability one-third of the entire run-off from 16,000 square miles of Sierra watershed is diverted for irrigation.

The diversion of so much water every spring and summer from the natural channels and the spreading of it on the porous soil has greatly changed the natural conditions with regard to the water table. As a direct result of heavy waterings when the works were new, the subsoil dry, and water both cheap and abundant, the water table has risen in places with astonishing rapidity, a rise of 20 feet in four years not being uncommon. It now fluctuates between 1 and 8 feet below the surface, while, before irrigation was practiced, well water was available only by digging or boring to considerable depths. If the surplus thus accumulated could readily be drawn off through either natural or artificial channels, and the ground water thus prevented from rising too high, such a filling of the subsoil with waste water would be beneficial in any district having an average annual rainfall of 9 inches, as is the case in this locality. The drainage of this district, however, is very poor; many of the deep creek channels and ravines that drain the foothill area of the Sierras widen as the slope of the land decreases and disappear entirely before the trough of the valley is reached. Only those streams, which have their origins far enough up in the mountains to provide continuous flows, have the level of their stream beds far enough below that of the surrounding country to admit of the land being drained naturally into them.

While irrigation has raised the ground-water level in the better drained portions, it has seldom brought it near enough to the roots of vines, fruit trees, and alfalfa to do much damage. It is where the drainage is poor that the ground water has risen and caused destruction to deep-rooted plants and trees. The presence of water too near the surface reduces the area which is available as a feeding ground for plants, dissolving the alkali, which exists more or less in all the soils of the arid region, keeping the soil moist continually by capillary attraction, thus inducing a more rapid rate of evaporation and drawing up the alkali through the soil to the surface. These losses, due to the rise of ground water and to the depositing of alkali, have reduced farm values in many cases from $350 to $20 per acre, and many 40-acre farms in the Fresno district have depreciated in value more than $12,000.

The object of the investigations herein summarized was to determine the practicability of systematic drainage as a remedy for the conditions described. The work was carried on by the Office of Experiment Stations in cooperation with the State of California, the expenses being shared equally. In addition to this cooperation, valuable assistance in materials furnished and work performed was received from John S. Dore and Lucius Baker, respective owners of the farms upon which the experiments were pursued. The directors of the Turlock and Modesto irrigation districts also aided greatly the work in ways described later.

This report is confined chiefly to a presentation of the important facts obtained from investigations carried on for the past two years in Fresno and Stanislaus counties. But the conditions as regards the needs of systematic, efficient drainage in the irrigated portions of both counties are so familiar to those in other portions of the San Joaquin Valley and the State in general that it is believed the results herein recorded, the conclusions reached, and the recommendations made will apply not only to the irrigated districts of the great interior valley of California but in a certain measure to all western lands under irrigation which are in need of protection from the evils resulting from the rise of the ground water.

DRAINAGE IN FRESNO COUNTY.

A VIEW OF THE AFFECTED DISTRICT.

Fresno County is known far and wide as the raisin center of California, the only State in the Union which produces raisins. The growth of this industry in this country during the past thirty years has been remarkable and there is good reason to believe that it will advance, perhaps not so rapidly, but at a rate sufficient to maintain a steady increase during the next thirty years. The yields of raisins in the Fresno district in pounds for the years named in the past decades are as follows:

Yields of raisins in the Fresno district, 1870 to 1900.

Year.	Pounds.
1870	None.
1880	1,500,000
1890	38,000,000
1900	94,325,000

Over 100,000 acres in Fresno County are devoted to growing raisins, wine, and table grapes. This part of the San Joaquin Valley is also well adapted to the growth of a wide variety of deciduous fruit trees. Although oranges and lemons for home use are grown, the chief dependence for profits from orchards is placed on peaches, apricots, figs, and olives.

It is likewise a district of diversified farms, where the profits from vineyards and orchards are increased by creamery products, the fattening of live stock, the keeping of poultry, and the raising of grain and grain hay on the dry farms. The disinterested investigator who has lived in Fresno city and realized its great commercial importance, and who has traveled over the country and observed the wealth of soil products which intelligent labor brings forth, is loath to direct the attention of the public to a part of the county that was once one of the show places of the State but which is now little more than a desert. Intensive irrigation, instead of establishing lasting monuments of agricultural wealth, has wrought destruction in this poorly drained district. Well-kept avenues lined with beautiful shade trees still lead out from the city to this affected district, but only dead stumps mark the place where valuable orchards and vineyards once flourished. Once comfortable farmhouses are falling to decay; stately California palms still stand like sentinels over deserted carriage drives, and the descendants of both Puritan and Cavalier, who once enjoyed large gains from vine and tree, have given place to foreigners who are content with the small returns to be had from the pasturing of Bermuda grass on alkali flats.

NECESSITY FOR DRAINAGE.

The subway recently built under the railroad tracks of the Southern Pacific Company within the corporate limits of Fresno affords a striking example of the need of drainage. This subway is 22 feet deep at its lowest point and nearly 600 feet long. Unusually heavy and costly construction was necessary on account of the height of the ground-water level and the large quantity of water which flowed into the excavation from the intersected sand strata underlying the hardpan. A pump having a capacity of 500 gallons per minute was operated continuously during construction, and when it was shut down for repairs or other causes the water level rose in twelve hours or less to its original level. This level on relatively high ground was 8 feet below the surface during part of the time of construction. Although unusual precautions were taken to build a boat-shaped structure for this subway with a concrete floor 2.5 feet thick and waterproofed, the ground water under a head of 14 feet is forced through this heavy lining and it is necessary to operate a pump during the entire year to remove the percolating water. Some of the first wells in Fresno were 65 feet deep and in many parts of the valley still unaffected by the waste from irrigation waters the ground water, except on the lower lands, varies all the way from 20 to 40 feet below the surface. Now in a large part of the residence district of Fresno it is impracticable to excavate cellars on account of the height of the ground water. In many of the basements under the business houses the continuous operation of pumps over extended periods is necessary in order to lower the ground water, and even then they can not be used for storage purposes.

THE PROBLEM CONFRONTING THE FARMER.

After canals had been built to furnish water for irrigation about 20,000 acres of white-ash lands in the vicinity of the Dore and Baker tracts were settled by colonists in small holdings of 10 to 40 acres, the greater part of each tract being planted usually to muscat grapes. Both soil and climate were admirably adapted to this variety of raisin grape, and for years this part of Fresno County was perhaps the best raisin district in the world. At this time vineyards were purchased for $350 per acre and were paid for by the profits of the crops in the first three years. Five years after water began to spread over the cultivated fields the water level was reported to be within 8 feet of the surface at certain places and ten years later it had risen to within 3 feet of the surface in the spring of the year. For over twenty years the landowners in the damaged districts south and southwest of Fresno have known that the ground water was steadily rising, but, strange as it may seem, they have done little or nothing to prevent this water-logging of the fertile soil. For a number of years this once prosperous and beautiful district has been seeded to Bermuda grass to afford pasture to dairy cows. The first settlers have as a rule sold their holdings to foreigners. On some tracts there are lingering attempts to raise muscats and on others a few trees bring in a small revenue, but it is questionable if the land in the entire district at the present time would pay interest on a valuation of $15 an acre. It is held, however, at figures varying from $20 to $40 an acre, the difference being due to probable future values when reclaimed by drainage.

The destruction of so much valuable plant life has been attributed to alkali, but it is clear that the alkalinity of the soil alone would have done little damage had it not been for the rise of the ground water close to the surface. In most of their schemes for the restoration of their land to a productive state the owners seem to have ignored drainage. They hoped to counteract the alkali with gypsum or by other chemical means to be discovered in the future. When these and other remedies failed to benefit other than the smallest tracts they folded their hands to wait for nature to undo the damage she had inflicted. A study of the root conditions in the affected soils, coupled with a study of the analyses of the soils before and after flooding, and observing the improvements in vines on drained lands that still contain the original quantity of alkali with the water removed from the first 4 feet or so of the soil, leads to the conclusion that while detrimental effects of alkali may not be overrated the injurious effects of high underground waters are greatly underrated. Even if it were possible to remove the alkali crust from the surface, the vines could not be restored to a healthy state without drainage. No plants other than aquatics will thrive if their roots are in a constant bath of pure water, much less in one of water strongly impregnated with alkali. The ground water in the affected district begins to rise as early as January and stands at a greater or less height until August, and the roots of the trees and vines are thus submerged in alkaline water during their entire active period and part of their dormancy. This causes the roots of the plants to occupy an unnatural position. The natural tendency of roots is to go toward damp soil or water, but they do not naturally go much beyond the depths at which the soil becomes saturated with ground water. The roots of the grapevine when normal consist of several branches that grow laterally and downward from the cuttings. When the ground water rises, however, they are forced upward and spread out laterally. The constant contact of water also causes the roots that are submerged to rot. Consequently, vines that were planted before the ground water became high and have survived the water and alkali have changed their root systems. The deep roots have been rotted off by the action of water, the remainder have spread out in an area 2 or 3 feet from the surface, and the plant is limited to a feeding ground strongly impregnated with alkali.

EFFORTS TO BETTER CONDITIONS.

The number of farms damaged by the rise of the ground water and the resulting accumulation of salts on the surface was at first small, but the area has gradually widened until now probably more than 60,000 acres are affected. As tract after tract became worthless for vines, fruit trees, or alfalfa, new tracts of larger size on better-drained soil were planted, so that both the fruit and grape industries have made rapid progress in spite of the loss of so large an acreage.

This Office first became aware of the conditions of the soil in the region southwest of Fresno City in 1901. It was urged at that time by private citizens and the Fresno Chamber of Commerce to make surveys and investigate the water-logged area. Work, however, was not begun until the summer of 1902, at which time Prof. O. V. P. Stout, acting under directions from this Office, conducted a survey to determine the surface conditions, the occurrence of hardpan, the height of the ground-water table, and all general information bearing on the drainage of 28,000 acres. The results of this survey were summarized by Mr. C. G. Elliott, of this Office, in Circular No. 50 and also in Bulletin No. 147 of the Office of Experiment Stations.

After the results of this survey had been published an effort was made to organize a drainage district, as recommended in the report, but the territory to be included was only the area that had been so greatly damaged. The landowners had practically ceased farming and were relying on dairying to give them some revenue from the land, hence they did not favor a scheme to bond the land for a purpose with which they were not familiar. For the most part they were ignorant of the profit to be derived from the lands if they were successfully drained, and there was no case available for citation showing them that drainage would solve the problem. Their skepticism was natural, and the opposition which it created, when united with that of the owners of certain large estates within the proposed district, defeated the measure. It was then evident that some practical demonstration along drainage lines would be necessary to show what could be done with the land. This Office was requested to make such investigations and conduct such experiments as would either prove or disprove the practicability of organizing a drainage district.

Until within the past year or two nearly all plans for the reclamation of lands around Fresno have been confined to the district damaged by alkali and lying south and southwest of the city. As this belt of 30,000 acres became nonproductive the vineyardists and orchardists gradually shifted to the east of Fresno until that district has become the most productive and highest developed section in the county. The soil there is a red sandy loam, not underlaid with alkali formation that would cause any damaging accumulation of salts on the surface, but drainage conditions are very similar to those in the alkali belt and the ground water is gradually rising nearer the surface. Vines and trees are failing, and, since there is no great amount of alkali to which to attribute the damage, people living east of Fresno are compelled to recognize the cause as a lack of drainage, and now there is a strong sentiment in favor of a concerted drainage undertaking. This has changed the plan from a small project to one which should include the drainage of more than 200,000 acres around Fresno. The sentiment, while in a measure due to the results obtained by this Office, has been strengthened by the installation of several individual drainage systems which have been beneficial, despite the fact that they were of too small capacity to remove all the water from the soil.

Concerted action to provide drainage has been much retarded by the importance which has been placed on subirrigation. The reason assigned for not applying water in particular localities was that the soil was kept sufficiently moist by natural subirrigation and needed no surface wetting. Land agents and others interested in country realty were wont to refer to this as a decided advantage, and as a result the belief became quite general that the presence of ground water so near the roots of plants was not a matter which called for attention. There are, it is true, a few localities in the arid region where natural subirrigation is beneficial, as the height of the water table can be controlled and submerging the roots of plants can be prevented. This condition prevails only to a limited extent around Fresno, and in too many cases subirrigation has but marked a stage in the rise of ground water from a deep subsoil to within a few inches of the surface. The subirrigated lands of one season usually become the water-logged lands of succeeding seasons.

SELECTION OF TYPICAL TRACTS FOR EXPERIMENTS.

In the fall of 1906 this Office began work on experiments to determine a proper system for the drainage of this land and the removal of damaging alkali. Two tracts, one the Lucius Baker and the other the John S. Dore tract, were secured for experiments to be made in cooperation with the respective owners. These tracts were representative of two typical conditions.

The Lucius Baker tract of 20 acres is located at the corner of North and Elm avenues, 2.5 miles south of Fresno. On this tract hardpan outcroppings appeared in places, while in other places there were patches of deep soil. The lay of the land made it difficult to flood and the accumulation of alkali was probably heavier than on any other tract in the affected district. About 10 acres of this tract had never produced good crops of any kind and practically no profits had been derived for several years. The soil was crusted with alkali, part was barren of any vegetation, and only salt grass grew on the balance. The tract represented the worst type of land to treat, and if it could be made to produce crops there would be no doubt of the effectiveness of the method employed.

On the John S. Dore tract the conditions were different yet representative of a large portion of the affected district. This tract, located 7 miles southwest of Fresno, consisted of 40 acres in muscat grapes. The problem here was to find a scheme to restore vines that were declining in value and productiveness due to rising ground water and the resulting accumulation of alkali, and to prove also whether or not such vines would regain their former state of productiveness. The tract had not been irrigated for fifteen years, which fact, coupled with excellent tillage for that section, had retarded the damage from alkali. However, the vines had been failing rapidly for the past three or four years and a plat of about 3 acres

O DISTRICT, SHO

was entirely without vines. This plat produced alfalfa for a time, but had finally become entirely barren. The areas affected by rising ground waters were increasing steadily each year and diminishing gradually the acreage of producing muscats.

THE GROUND WATER.

After the first examination it was evident that the right solution of the drainage problem in the Fresno district would necessitate a careful study of the ground-water conditions. In the spring of 1904 seven test wells 6 feet deep, cased with lumber, were dug on Fruit avenue (map, Pl. I) one-half mile apart, under the direction of Mr. C. G. Elliott, of this Office. Observations on the water levels in these wells were made from March 1 to September 1, 1904, when the water table fell below the bottom of the wells. The results are shown in profile on the accompanying chart (fig. 1).

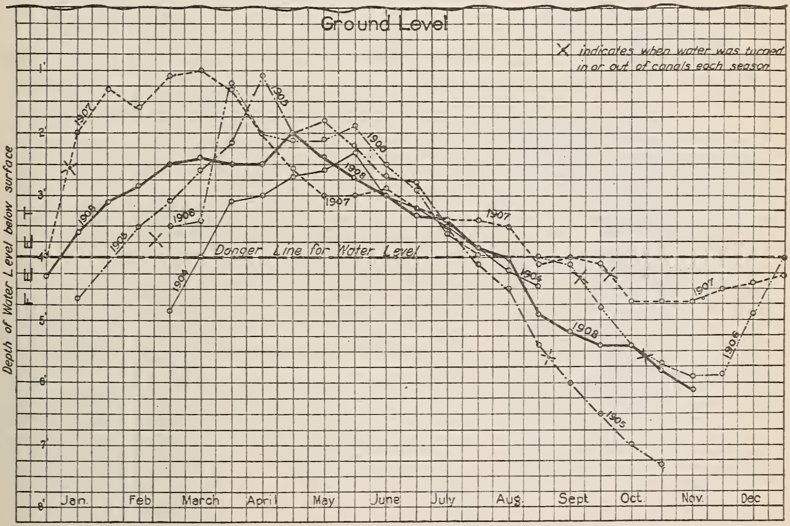
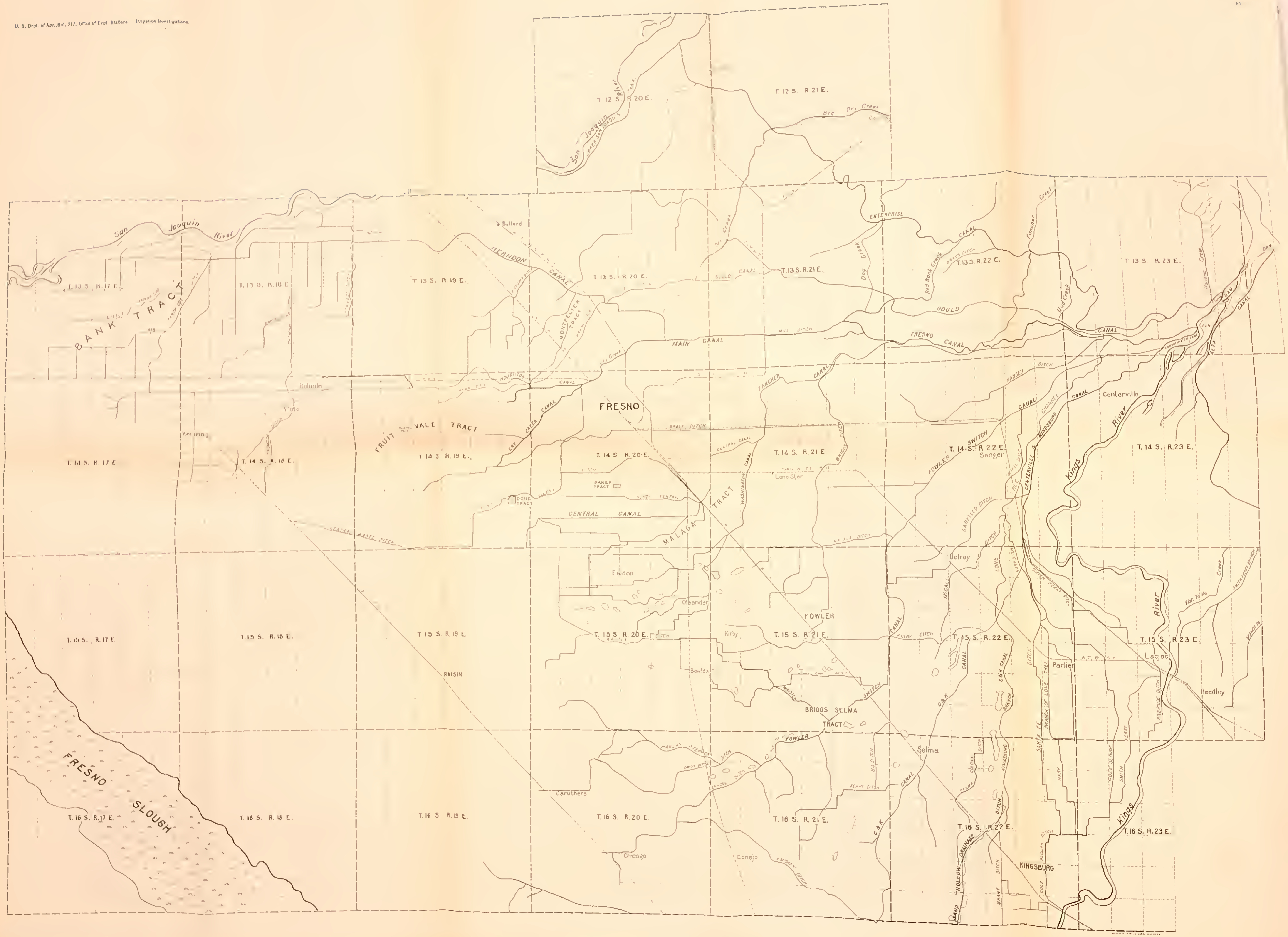


FIG. 1.—Ground water levels in Fresno district, 1904 to 1908.

In the fall of 1906, after the Dore and Baker tracts had been selected, many more test wells were established at one-eighth mile intervals in the immediate vicinity of these tracts. These wells were bored through the hardpan to a depth of 10 feet by means of the special auger shown in figure 2 and cased with light 4-inch galvanized-iron tubing. A stake was driven at each well to serve as a level bench, and all benches were connected by a line of levels. The distance from the top of the stake to the surface of water in the well

U. S. Dept. of Agr., Bul. 217, Office of Expt. Stations. Irrigation Investigations.



MAP OF FRESNO DISTRICT SHOWING IRRIGATION CANALS.

was measured weekly and recorded. These records, shown in the profile of the accompanying chart (fig. 1), for the years 1906, 1907, and 1908 represent the average weekly measurements of some 60 wells. This large number was necessary in order to eliminate variations in particular wells arising from purely local causes, such as the irrigation of lands around the well, proximity to canals, etc.

A depth of 4 feet from the surface is assumed as the danger line of the water table for raisin and wine grapes, and the profiles show that the ground water was above this line continuously from March to August of each year during which well records were taken. This period includes the greater part of the growing season for the prevailing crops of the Fresno district. Trees and vines pass from their dormant state in March and part of the fruit is marketed in August, while nearly all the crops are mature the latter part of August or early in September. Thus it is seen that from March to August the ground water is too high to permit plants to make the growth they would if their roots had been in deeper feeding ground. But still more injurious is the extremely high water through May and June, which leaves only 18 to 36 inches of soil for the root systems to feed upon. It is not surprising that vines and trees fail to produce profitable returns and eventually die when their deeper roots are destroyed by being submerged for long periods or when their shallow roots are more or less injured by mineral salts which have accumulated in the top layer of the soil.

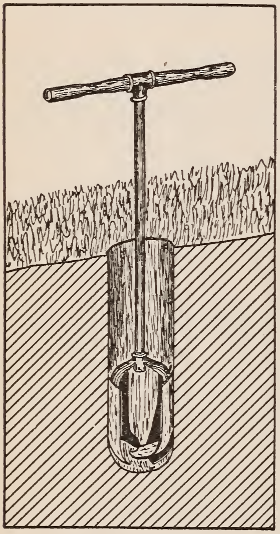


FIG. 2.—Soil auger.

The record of the water table for November and December, 1907, is very interesting because it shows the water table to have been more than a foot higher than during the corresponding low-water period of the year previous and the year following. From the rainfall record it is also seen that the precipitation for the winter of 1907 was less than for the previous year. This abnormal rise of a foot in the water table is doubtless due to the irrigation canals running water through the fall months of 1907, while in the other years the water was turned out in September or October and was not turned back into the canals until the first of the year. The canals carried some water throughout the fall months of 1907, but practically all the laterals began running a full head during the second week of February, 1908.

A summary of the records of the water level from 1904 to 1908, inclusive, is as follows:

(1) The time of lowest ground water varies from October 15 to December 15.

(2) The present fluctuation of the water table varies from 3.5 to 6 feet, according to the amount of rainfall and the time when irrigation water is turned in and out of canals.

(3) The most rapid rise in the water table occurs during January, February, or March, the average normal maximum rise for any one week being about 0.6 foot.

(4) The water table generally falls below the danger line in August.

(5) The maximum average daily rise in the water table for the four months of January to April, inclusive, of any one season was 0.025 foot.

The following table has been compiled to show the rainfall for each rainy season instead of for the calendar year. The level of the ground water for any one growing season is affected, it is believed, by the precipitation of the entire preceding rainy season.

Monthly precipitation at Fresno.

Month.	1903–4.	1904–5.	1905–6.	1906–7.	1907–8.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
July	0	0	0	Trace.	0
August	0	0	0	0	Trace.
September	0	1.78	Trace.	Trace.	Trace.
October	0	3.21	0	0	1.08
November	0.68	.08	0.96	0.73	0
December	.22	1.12	.41	3.16	.97
January	.57	.93	2.05	3.35	1.70
February	2.49	.90	2.20	.94	1.75
March	2.75	2.04	4.10	1.74	.71
April	1.21	.45	.92	.69	.80
May	.12	1.58	2.88	Trace.	.63
June	0	0	Trace.	.24	0
Season	8.04	12.09	13.52	10.85	7.64

The funds available for the work would not permit those in charge to keep a continuous record of the volumes of water carried by the main canals and their distributaries (see map, p. 15) throughout the Fresno district during the years when well records were taken. Record of the quantities of water conveyed to different parts of the district and the time when it was distributed over the land would have aided greatly in interpreting correctly the fluctuations of the ground water. The facts collected were confined chiefly to the time when water was first turned into the canals at the beginning of each irrigating season and the time when it was turned out, and these dates are given on the page following.

Dates when water was turned into and out of Fresno canals.

1904.—Water turned in canals first week in January.
1904.—Water turned out of canals second week in September.
1905.—Water turned out of canals first week in September.
1906.—Water turned in canals second week in February.
1906.—Water turned out of canals third week in September.
1907.—Water turned in canals second week in January.
1907.—Water turned out of canals first week in October.
1907.—Water turned in canals second week in November.
1908.—Very little water in August.
1908.—Water turned out of canals completely second week in October.

Opinions differ as to the chief sources of the ground water and the causes which produce its rise and fall. The investigations were not planned or executed with a view of determining this, but to locate the ground-water table and to observe its rise and fall through the longest possible period. It was believed that the proprietor whose land was being damaged would be chiefly concerned with the rise of the ground water and how to prevent it from submerging the roots of his most valuable crops. At the same time the authors realized the importance of tracing the ground water back to its various sources, in the hope that a part of the present water might be saved and made to serve the twofold purpose of preventing valuable lands from being water-logged and of furnishing a supply to other lands that are too dry to be productive. While no definite conclusions were reached on this subject, the statements which follow may serve to throw some additional light on the prevailing conditions and aid those who are seeking a remedy.

The rise of the ground-water level over a large area from a depth of 45 feet or more to within 2 or 3 feet of the surface can not well be attributed to the rainfall, which has varied little during the last fifty years. The only possible change in the level due to rainfall would arise from the tilling of the soil, which would cause more of the rainfall to be absorbed by the soil; but it is believed that this added supply from rainfall would not produce much effect on the water table. By experiment it was found that 1 inch of rainfall would saturate 4 inches of soil, or, in other words, 1 inch of rainfall would cause a rise of 4 inches in the water table, provided it all went into the soil. The mean annual rainfall at Fresno is about 9 inches per season and, according to the foregoing, if this amount were applied at one time without loss by run-off or evaporation, it would raise the water table only 3 feet.

Occasionally floods occur in the shallow creeks and ravines which drain the foothills above the Fresno district. When in flood these shallow channels discharge considerable volumes over the surface of the lower lands, and a part of this water naturally joins the ground water and raises its level. If it can be shown that these floods have been more frequent of late years than formerly it would tend to show that this was one of the causes of the high-ground water. Such evidence is wanting, however.

The data collected thus far seem to point to the conclusion that the water conveyed by the irrigation channels is the chief source of the ground water and that the spreading of this water over the surface in irrigating crops is the chief cause of the rise of the water table.

A glance at the map (Pl. I, p. 15) will convey some idea of the extent of the irrigation channels. In the height of the irrigation season a continuous flow of 1,500 cubic feet per second is distributed over the district. A large part of this is wasted, and the greater part of this waste water sinks into the sandy soil and joins the ground water. Many believe that the bulk of the ground water comes from the irrigation channels by seeping through the bottoms and sides. The facts collected by the writers show that much more irrigation water joins the ground water as the result of percolation from irrigated fields than from seepage along ditches and canals. There are doubtless parts of several water channels where there are considerable volumes of seepage, but the results of measurements made on the Central Canal (Pl. I, p. 15) in the summer of 1907 showed the loss in 2 miles to be too small to consider.

GENERAL PLAN OF EXPERIMENTS.

The natural fall of the country is about 5 feet per mile, which would permit of a great volume of water draining through the sandy soil if there were no obstructions. The district is, however, generally underlain with hardpan of varying thicknesses and at varying depths. In places it outcrops on the surface, while a short distance away it may be covered with 6 to 10 feet of soil. This rolling, wave-like nature of the hardpan prevents the natural subdrainage of the soil that would be otherwise produced by the fall of the country. The crests of hardpan serve as underground dams which prevent the natural drainage action, causing the ground water to rise near the surface, bringing with it large quantities of alkali.

The nearest natural water course into which a gravity-drainage system could discharge is about 20 miles from the experimental tracts, and it was quite impracticable to construct an open canal that distance for two small tracts of land. Plans were first made to drain the water into sumps, then install gasoline pumping plants, and pump the water to a surface ditch or canal, but owing to the difficulties involved and the added cost of operation a different scheme was decided upon.

Measures were taken to induce the San Joaquin Land and Power Company to extend a pole line into the affected district. Through the earnest solicitations of Hon. J. C. Needham, Congressman for the district, and several influential men of Fresno County, the power company built a line 7 miles long, at a total cost of $3,500, and capable of transmitting sufficient current to meet the needs of all the farmers living along the route for both power and light. This pole line was placed purposely along the southern boundary of each experimental tract, so that the current when reduced in voltage might be available to drive motors for pumping drainage water.

The general plan of the work on both tracts was to lay tile drain as deep as practicable and have each system connect at the lowest end with a sump, from which the drainage water was to be pumped through a discharge pipe to the nearest irrigation canal. The plans also comprised the checking of the surface of each tract by a system of levees, so that each check might be flooded to a depth of 12 inches. To provide water for such flooding, the farm ditches were to be enlarged and extended.

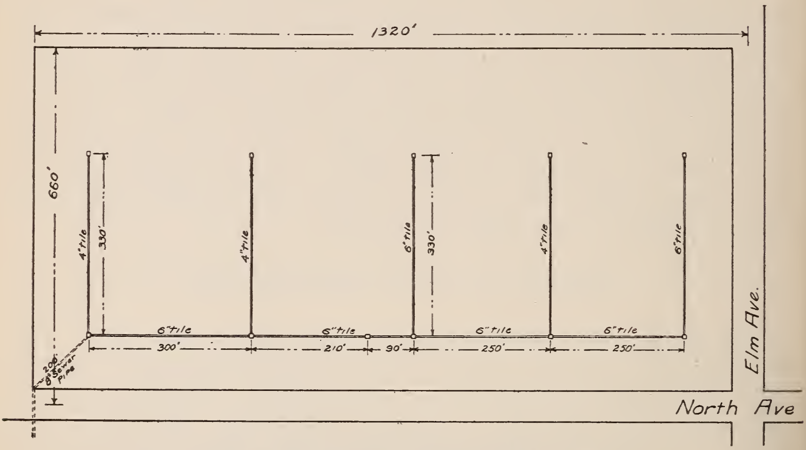


Fig. 3.—Plat of Baker tract showing tile lines.

On the Baker tract (fig. 3) the sump was placed on rather high ground near the southwest corner of the 20-acre tract, in order that the water pumped might be most readily disposed of. The tile system consisted of a 6-inch tile main running 1,100 feet east from the sump, with five lateral branches, two of 6-inch and three of 4-inch tile, running north. A 3-inch vertical centrifugal pump was placed in the bottom of the sump. The vertical shaft running to the surface was connected by belt to a 3-horsepower electric motor, located 12 feet from the sump. The motor was housed in a ventilated box just large enough to shelter it from the weather, and the belt was covered with an inverted trough running horizontally from the motor house to the pump shaft. The pump was without suction pipe, but was primed by the water rising in the sump and covering the runner. The water was brought to the surface through a 4-inch pipe and discharged into a Cipoletti weir box 60 inches long, 30 inches wide, and 12 inches deep, fitted with an automatic gauge. From the weir the water was conveyed through an 8-inch sewer pipe to an open ditch. For the drainage of this tract 1,760 feet of 6-inch drain tile, 990 feet of 4-inch drain tile, and 200 feet of 8-inch sewer pipe for discharge line were needed.

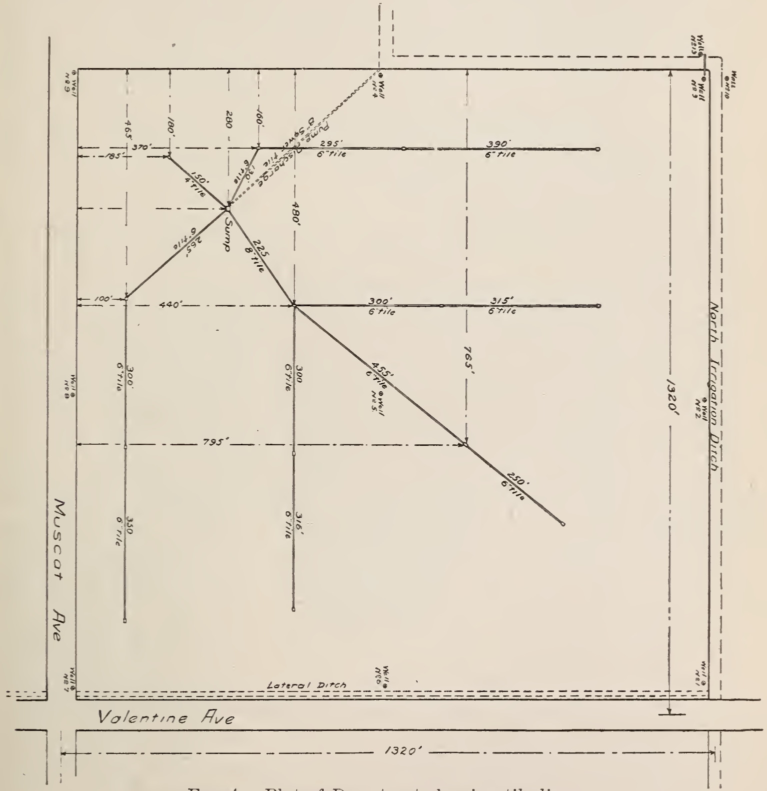


FIG. 4.—Plat of Dore tract showing tile lines.

On the Dore tract the tile lines were laid in the general direction of the flow of the underground water, and the sump was placed as close to the discharge ditch as the lay of the land permitted. The scheme of drainage (fig. 4) was very similar to that of the Baker tract, the tile being distributed so as to drain the entire 40 acres.

A 3-inch vertical centrifugal pump was placed in the bottom of a sump 8 feet square and 9 feet deep. The vertical shaft of the pump was connected in a manner similar to that on the Baker tract, the motor being 10 feet from the pump shaft. A very valuable feature of this pump is a ball-bearing attachment, supported on the skidding, which takes up the weight of the shaft and runner. The balls are immersed in oil, reducing the friction and requiring very little attention. The ball bearing is equipped with a screw coupling, which permits of a fine adjustment being quickly obtained. It gave excellent service, and one was secured for the Baker pump also. The Dore pump discharged into a weir box equipped in the same manner as that at the Baker tract. The completed system for the drainage of the Dore 40 acres required 3,665 feet of 6-inch drain tile, 225 feet of 8-inch drain tile, 150 feet of 4-inch drain tile, and 425 feet of 8-inch sewer pipe for the discharge line.

DETAILS OF CONSTRUCTING THE TILE-DRAINAGE SYSTEMS.

The location of the lines of tile on the Baker and Dore tracts was decided after a thorough surface and soil survey had been made. Borings 6 feet in depth were made with a 1½-inch auger at intervals of 25 to 200 feet to determine the presence of hardpan and sand swales that would impede or assist drainage. Levels were run to determine the surface slope in order that ditches might be constructed at a practical depth with as little moving of dirt as possible. The information obtained from these surveys, combined with a consideration of the facilities for discharging the water from the pump, decided the location and depth of the sumps. These were excavated 8 feet square and 8 to 9 feet deep and lined with 2-inch redwood braced with crosspieces to prevent caving.

Center stakes were set where each tile line was to be laid. At a distance of 20 inches from the center stakes a parallel line of grade stakes was set. The stakes were set 50 feet apart and driven to such a depth that a line stretched along their tops would have the desired slope for the tile. The tile trenches were dug with pick and shovel, the sump being the starting point. The depth of the ditch at that point was such that the tile at the other end of the line would be at least 3.5 feet below the surface after allowing for the slope. The depth at which the tile was to be laid from the line stretched along the grade stakes was determined by means of a gauge consisting of a vertical rod with an arm at right angles to it. When the horizontal arm was placed on top of the grade line and the rod held vertical, the foot of the rod gave the grade for the tile. When the bottom of the trench was in firm soil, a tile scoop was used to make a semicircular trench to fit the tile, but where soft, wet soil was encountered it was necessary to lay a board in the bottom of the trench for a tile base. The tile was then laid upgrade, care being taken to have the ends butted close together and in good alignment. As the tile was laid the joints were covered with tar paper on the upper two-thirds of the circumference and a few inches of dirt placed on them to prevent their being moved. The balance of the ditch was then filled by a team drawing a V or filling scraper. A $\frac{1}{4}$-inch wire cable for cleaning purposes was inserted in the tile as it was being laid. When from 250 to 500 feet of tile had been laid, or at a place where lateral lines of tile were to enter the main line, sand or silt boxes were placed in the ground, extending 1 foot below the tile (fig. 5). These boxes serve to collect the sand or silt which enters the tile and to divide the line of tile into sections, so that the wire cable can be operated freely. The boxes were rectangular, being 30 by 60 inches, and built of 2-inch plank in sections, the width of the board, thus making it easy to place them. Corner pieces prevented them from moving, and wooden bottoms were provided when hardpan did not occur in the bottom of the pit.

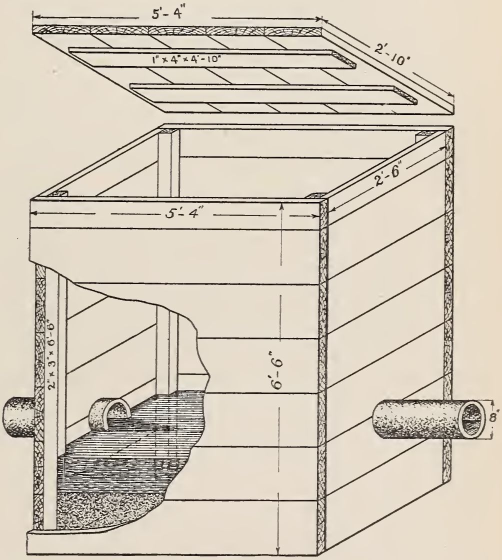


FIG. 5.—Sand box in tile line.

The work of constructing the two tile systems was commenced in the fall of 1906 when the ground water was about 7 feet below the surface, some of the tile being laid at that time. The smaller tile did not arrive until after the first of the year when the winter rains had caused the ground water to rise above the depth at which the tile was to be laid. An attempt was made to lay the tile in order that the drainage plants might be operated the following summer. The sandy soil was thoroughly saturated and a power pump had to be operated to drain the water from the ditches as they were being dug. The workmen had to wear rubber boots, impeding their progress; the soil weighed more, making it harder to handle, and the walls of the ditches caved badly. Water in the ditches made the bottoms soft, and it was difficult to obtain a good grade for the tile or to make good joints. Silt and sand got into the tile even when the ends were placed as close together as possible. When laid under water the trouble was still greater, as great care could not be used to make good joints. When the soil was dry the ditch walls would stand for several days without caving even when opened to a depth of 5 to 7 feet. But when the ground water was high and the subsoil well saturated the soil became so heavy as to be unable to support its own weight, and the walls of the ditches began to cave when they were opened to a depth of 2 or 3 feet. This was especially true of the more sandy soils, and boards had to be placed against the walls with firm cross bracing to prevent the caving. This shoring took considerable time and the braces interfered with the excavation of the bottom part of the ditches. It was necessary also to make the ditches wider than in dry ground, and when the pump stopped from any cause the entire work was delayed. When quicksand was encountered in the bottom of a wet ditch it would flow in from the sides so rapidly as to make it almost impossible to lay boards to support the tile. In that case it was necessary to lay boards at the sides of the tiling. When the water table was 2 or 3 feet above the grade of the tile the conditions of the soil were so bad that much mud got into the tile while it was being laid. The caving of the banks and the refilling of the ditch misplaced the tile that had been laid and poor alignment was obtained throughout. As a consequence, when the tile lines were completed nearly all of them were so clogged with silt that the cable could not be drawn through. The larger tile which had been laid when the ground water was low gave excellent service.

Practically all of the tile which was laid in the mud was dug up and the line relaid in October, 1907, when the water table was low. Most of the 4-inch tile was replaced with 6-inch at this time, for it was found that inferior drainage resulted from the use of the smaller tile. The completed system has given no trouble since it was remodeled, and the drainage service has been all that was desired.

LAYING TILE IN HARDPAN.

Although the Baker tract was chosen for an experiment tract because of its barren state and the hardpan was known to be close to the surface, the part it would play in the reclamation work was unknown. It was found that with the exception of a small sand swale the entire tract was underlain with hardpan of varying thickness, and on the east side of the tract it was exposed on the surface. This proved to be a very serious hindrance to the drainage action, as the hardpan was principally above the tile. When the surface was flooded to remove the accumulation of alkali the rate of percolation of water into the soil was slow, only 2 or 3 inches going into the soil in twenty-four hours. The alkali, therefore, was leached out very slowly, and subsequent analyses showed that the salts washed from the surface down through the soil collected near the hardpan. As soon as the water was removed from the surface and evaporation again became heavy the greater part of the alkali was returned to the surface. This land was flooded for a period of three months in the spring of 1907 without interruption other than for the purpose of cultivating the soil at intervals to break up the silted surface. When this flooding period was over, little benefit was shown by the sample taken where the hardpan was near the surface. The soil dried very rapidly after the water was removed from the surface, and seed planted under such conditions gave slight returns. In places the soil was too dry to allow much of the seed to germinate. The plants that did get a start amounted to little because the hardpan prevented moisture from rising to the growing plant and did not give the roots room to grow and feed.

BLASTING HARDPAN.

The reclamation of such land necessitated a radical treatment of the hardpan. In the spring of 1908 a portion of the tract was blasted in order to break up the hardpan and was then flooded for two weeks. Analyses of samples taken from each check after this flooding shows that more alkali was moved in these two weeks of flooding than in the three months of flooding before the hardpan was broken up. This result was predicted from the fact that about 10 inches of water went into the soil in twenty-four hours after blasting, where but 3 inches went into the soil in a like time before. The results also showed that the blasts were too light and were placed too far apart, as undisturbed strips of hardpan were left between the blasts and the action was not so complete as it would have been had all the hardpan been broken up. The denseness and thickness of the hardpan will govern the amount of dynamite to be used and the proper placing of the same to give the greatest efficiency. The hole should stop within 4 or 5 inches of the bottom, so that the charge will just blow through and shatter the bottom of the hardpan and utilize the greater portion of the force in breaking up the hardpan above the charge. If the charge is placed under the hardpan the force will be spent in the sand underlying the hardpan and will not shatter the hardpan to any extent. When properly placed the blast should give a muffled report, and though the soil will be well loosened very little earth should be thrown into the air.

It was found by measurement that the effect of the blasts in breaking up the hardpan extended over an area 32 to 38 feet in diameter, or each blast would effectually break up an approximate area of 800 to 1,100 square feet. The decreasing effectiveness in the breaking up of the soil and the unaffected spaces between the areas broken up indicate that from forty to fifty-five shots per acre should be used in order to insure a thorough breaking up of the hardpan.

The approximate cost of each blast is:

Cost of blasting hardpan.

½ pound dynamite per blast	$0.085
5 feet of fuse	.040
1 dynamite cap	.008
Labor for each blast	.117
Total	.250

or from $10 to $13.75 per acre.

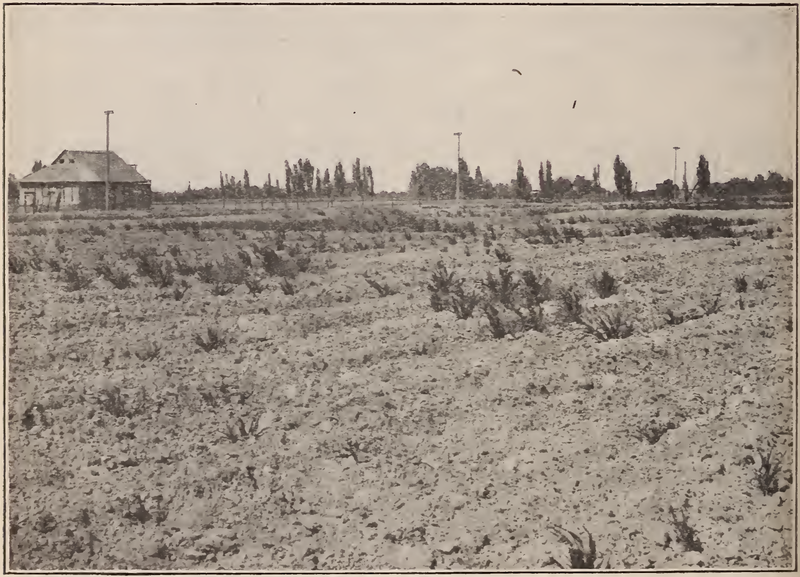


FIG. 6.—Showing spotted growth of Egyptian corn due to blasting.

If properly handled, this blasting should break up the hardpan quite uniformly, permitting roots to grow through and greatly facilitating the passage of water through the soil.

Figure 6 shows the spotted growth of Egyptian corn planted on land where a few widely separated blasts were placed. Moisture was permitted to rise through the shattered hardpan and the plants grew, while the lack of water elsewhere prevented growth. The effects of the blasts were easily traced by changes in the color of the soil. After blasting and flooding, the land was plowed. The soil around each blast was a light gray; outside of this was a ring of darker soil; then another circular band of still darker soil; and away from the influence of the blast, where the hardpan was not disturbed, the soil was a darker brown, which extended to the outer circle of the next blast. This indicated the drainage benefit derived from the blast. The following set of analyses of soil samples taken after this flooding bears out the deductions drawn from the color of the soil. Samples 1 and 4 were taken from the area beyond the influence of the blasts; samples 3 and 6 were taken near the center of the broken-up area, where the greatest drainage influence was derived; while samples 2 and 5 represent the intermediate spaces. A separate sample was taken from each foot in depth for a depth of 4 feet, the letters a, b, c, and d representing the first, second, third, and fourth foot, respectively.

Analyses showing effect of blasting hardpan.

Number of sample.	Per cent of salts.	Number of sample.	Per cent of salts.	Number of sample.	Per cent of salts.
1a	0.072	3a	0.062	5a	0.060
1b	.125	3b	.064	5b	.090
1c	.095	3c	.016	5c	.065
1d	.095	3d	.012	5d	.065
2a	.062	4a	.070	6a	.053
2b	.092	4b	.120	6b	.074
2c	.085	4c	.085	6c	.060
2d	.076	4d	.080	6d	.050

It will be noted that in the above table the greatest benefit derived is obtained in the second (b), third (c), and fourth (d) foot of soil. The increased drainage resulting from this breaking up of the hardpan allowed the salts to be leached from the soil where it was practically impossible before. And while alkali salts were carried down through the lower sections of the soil during the flooding season, a small percentage was drawn back to the surface by the action of capillary attraction and evaporation after the flooding was discontinued.

REMOVAL OF ALKALI.

After the tile systems had been constructed and the pump put into operation the next step was to remove the excess alkali from the soil. The land was laid out in checks, with a sufficient number of levees to permit a depth of 1 foot of water to be run on to the land. The Dore tract was quite level and fewer levees were needed to insure the required depth, the levees being thrown up with a "V" scraper in the vineyard roads (fig. 7). On the Baker tract, where smaller checks and higher levees were needed in places, much of the levee work was done with a scraper. The land was then plowed, water was turned into the checks, and as many were flooded at one time as the supply of water would permit. The best results were obtained when the water was kept at a height of 1 foot, and but little benefit resulted from flooding the land with only a few inches of water. The pressure due to the greater depth of water forces more water into the soil and also leaches out more alkali.

One of the chief difficulties in the reclamation work was due to the alkali rendering the surface of the soil more impervious to water. The soil that was crusted with alkali silted over when water was applied and after it had been constantly covered for a few days very little water would enter. After running the water off and cultivating the surface the percolation was fairly rapid for a few days after the flooding was resumed, but it became gradually less until after a week or so the cultivation had to be repeated. As the salts became leached from the surface, the soil became more porous, and in the last stages of the flooding operation the rate of percolation through the soil continued great enough to render interruptions for cultivation unnecessary, even after two or three weeks of continuous flooding.

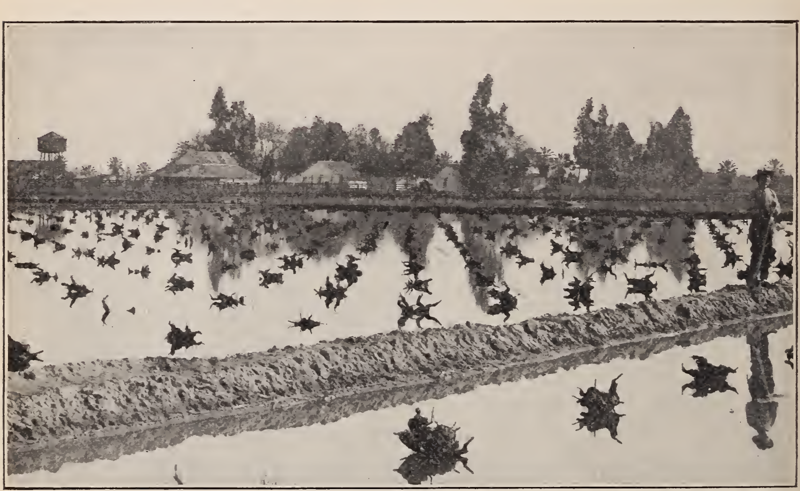


FIG. 7.—Dore tract during flooding, showing character of levees.

Great stress must be laid upon the proper cultivation of the soil, not only for securing the greatest crop production, preserving the usefulness of the soil, and preventing the rise of alkali to the surface, but also for obtaining the best results and greatest economy in taking the excess of alkali from the land during the flooding process.

It is common practice in Fresno County to plow about 4 inches deep and in cultivating to just scratch the surface of the land to break the clods and make the surface look smooth. This cultivation does not require large horses, and consequently smaller ones, which are cheaper and cost less to feed, are the ones most common on the ranches. One excuse for not cultivating deeper is that the horses can not do deep cultivation.

This shallow cultivation has been the rule for years, and as a result a plow pan of greater or less thickness has been formed. This plow pan is very detrimental both to crops and the work of reclamation. When an attempt was made to drive the alkali through the soil by flooding the surface, it was found that this plow pan prevented the descent of the water. When flooding was stopped and the land was cultivated to overcome the silted surface, the soil next to the plow pan was almost as strong with alkali as the original soil crust. Consequently it was necessary that the plow pan be thoroughly broken before water was applied again. The use of the subsoiler following the plow broke the ground to a depth of 18 inches and destroyed this formation. Cultivators that stirred the soil 8 or 10 inches in depth were used then.

When the land first silted during the flooding no more water was added, but the water in the check was allowed to seep away into the soil without draining any of it from the surface. Puddles formed in the low places as the water sank away, leaving the higher places exposed and badly crusted. The evaporation had caused a flow of water upward, bringing the alkali to the surface until the soil appeared to contain as much alkali as before the flooding commenced. When it became necessary to turn the water off for a second cultivation the water was allowed to subside until it barely covered the highest places in the checks; then as much as possible of the remainder was drained into an irrigation ditch. The small puddles were drained into the tile system by taking off a section of each silt box and running plow furrows or small ditches to the boxes. This method permitted the surface to dry uniformly, and as soon as a team could go on the land the surface was cultivated lightly to prevent crusting. Within two or three days the soil was dry enough and was plowed to a good depth, after which the water was turned on again. This treatment prevented much surface crusting and accumulation of alkali due to evaporation. The Dore tract was flooded ten days during the spring of 1907, but no more, because of the poor condition of the soil and the putting forth of shoots by the grapevines. The Baker tract was flooded intermittently until well into the summer, there being no crop to interfere.

After the tile system had been reconstructed and extended flooding was commenced in the fall of 1907 by pumping from deep wells on the tract with a 6-inch centrifugal pump and portable engine, and continued for thirty days. After the pumps were stopped the flooding was continued by gravity flow from irrigation canals until the first week of March, 1908, when the bare land was considered to be in condition for planting and the vineyard had begun to put out shoots.

CLEANING TILE.

As the water level is lowered by the drainage system the roots of the vines and trees will follow down and in the course of time will find their way into the tile through the joints. These fine rootlets, if allowed to collect, will stop the flow of water and render the tile useless. It is out of the question to locate such drains far enough from the trees or vines to be certain that the roots will not reach them, as the bulk of the tile drainage will be done in orchards and vineyards already planted. Provision must, therefore, be made to keep tile clean and free from roots, and for this purpose the wire cable previously mentioned is inserted in order that a wire brush may be dragged through. The cleaning force consists of two men and a steady horse, an extra length of cable, a wire brush, and rollers to attach to the silt boxes to prevent the cable from cutting the boxes as it passes over. The brush, the diameter of which is equal to that of the tile, consists of a wooden core with flexible steel bristles radiating from it and a ring at either end. The extra length of cable is attached to one end of the brush and the wire cable already in the tile fastened to the other end of the brush. The horse pulls the brush through the tile, leaving an extra cable in the tile until another cleaning is necessary. If the tile is badly clogged it will be best to draw the brush downstream in the tile, and it may have to be worked back and forth a short distance at a time until the water has washed out the material loosened. For the purpose of cutting roots from the tile it is best to draw the brush upstream because the flow of water has caused the roots to extend their length with the current, and the brush will cut them more easily. The water will back up while the brush is being drawn upstream and the sudden release of the accumulated volume when the brush reaches the silt box will wash the roots from the tile.

Such trees as willows and elms should not be allowed to grow near tile lines. The tile should be cleaned at least once a year, and in vineyards, orchards, and alfalfa it may be necessary to clean them each month to keep them in good condition. It may be advisable to coat the cable with some preparation to prevent wearing, due to the frequent use and continuous action of the water on it. This method of cleaning tile is inexpensive and efficient.

It has been proposed that a small wire be laid in the tile in place of the heavier cable in order to decrease the cost. This, however, is not advisable, because light cable or wire would not stand the strain of pulling the larger cable through the tile when clogged. The expense of digging up the tile and replacing the cable in case of breaks would amount to more than the extra cost of installing the heavier cable in the first place. Breaking the cable might result also in a delay of several weeks or even months before the water level would permit of excavation, and the damage due to loss of drainage in that line of tile might be considerable.

COST OF TILE WORK AT FRESNO.

To complete and reconstruct the tile system at Fresno 3,000 feet of 6-inch tile was used. This was one large car, purchased in San Francisco, the cost being as follows:

Cost of tile for experiments at Fresno.

3,000 pieces of tile, 6-inch	$286.40
Freight, 25 tons, at $2.95 per ton	73.75
Demurrage	4.00
Hauling from car	34.65
Total	398.80

This made the cost on the ground ready for laying 13.29 cents per foot. This tile was not of the best, the principal fault being that the ends were not cut true, making it impossible for the line to be straight if the joints were fitted properly.

At the Baker place there were five laterals, each 330 feet long, three of these being of 4-inch and the others replaced by 6-inch tile. There were 800 feet of 6-inch main relaid. This tile was laid under abnormal conditions and the cost data is therefore of little value. On the Dore tract conditions were more nearly normal, and the labor cost of laying tile on that tract is given below:

Labor cost of laying tile on the Dore tract.

Digging trenches and laying tile:		
92 days, at $2.50 per day	$230.00	
9 days, at $3 per day	27.00	$257.00
Filling trenches:		
Two men and team, 6½ days, at $6 per day	39.00	
Man with shovel in vines, 1 day, at $2.50 per day	2.50	41.50
Total		298.50

There were 2,300 feet of 6-inch tile laid. All of this was in vineyard where the dirt had to be thrown away from the vines. In filling the ditches a filling scraper was used, and the vines interfered with this work considerably. However, the cost of filling this 2,300 feet, $41.50, gives 1.8 cents per foot. The cost of digging the trenches and laying the tile was 11.2 cents per foot. This gives a total of 26.3 cents per foot for tile and all work connected with laying it and filling the trenches. The average depth of this 2,300 feet of tile was 4.5 feet.

The above data represent work in dry ground with the water table below the tile line, so as not to cause caving, but these figures included excavating a large amount of quite firm hardpan. If tile is laid in sand without hardpan, a base should be used. This would cost about 2 cents per foot, or about the same as the increased cost of digging in hardpan.

The cost of the cable inserted in all of the tile was about 2 cents per foot. With the average depth of tile 4.5 feet, the depth of sand boxes should be about 6 feet, because they should extend about 1 foot above the surface. Earth should be banked around to exclude flood water, and the boxes should extend at least 6 inches below the tile to serve as settling pools to catch the sand. Boxes of 2-inch redwood 30 by 60 inches, with cover and bottom, require about 215 feet board measure. (See fig. 5, p. 23.) This at $42.50 per 1,000 feet would amount to $9.15. Including nails, etc., the cost per box would be about $9.25; making and placing the box and excavating the hole would cost about $2, making a total of $11.25 for each box. Since a box is required about every 300 feet on the average, this would be at the rate of 3.75 cents per foot of tile. Then the cost per foot of tile in place for a complete system would be:

Cost of drains in place.

	Per foot.
Cost of tile in place	$0.2630
Cost of cable	.0200
Cost of sand boxes	.0375
Total	.3205

NECESSITY FOR CONTINUOUS OPERATION OF DRAINAGE PLANTS DURING HIGH WATER TABLE.

The fact is patent that in order to be of service a drainage pumping plant must be operated continuously. This fact was clearly shown at Fresno while the Dore tile system was being installed early in the spring of 1907. The ground water was within 3 feet of the surface when the tile work was commenced, and, as before stated, a power pump was necessary to keep the water away from the tile as it was being laid. As the tile system was extended the amount of water flowing in became greater and the pump had to be started about an hour before the pick and shovel men commenced work in order to get the sump and tile ditch well drained. The pump was thus run for about ten hours a day and the effect on the ground-water level was very noticeable in a cellar located about 800 feet west of the sump. During each ten hours of pumping the water in the cellar was lowered about a half inch, but before the pump was started the following day it had assumed the general ground-water level. This general ground-water level continued to rise during the entire time of construction work and stood about 22 inches below the surface. When the electrical plant was started, March 26, 1907, the general ground-water table was still rising, but the action of the pump was sufficient to cause a permanent lowering of the water in the cellar. At the end of the first seven days of continuous pumping the water had been lowered 7 inches.

A practical demonstration of the necessity for a continuous drainage, especially where alkali is encountered, is seen on a tract of land about 3.5 miles south of Fresno, where an alkali reclamation experiment was concluded in the fall of 1906. The plan of reclamation was essentially the same as that followed in the Fresno experiments conducted by this Office. The land borders on an irrigation canal carrying 40 cubic feet per second, and power to drive the pump is furnished by a water wheel placed in the canal. This wheel is connected by a chain drive to a centrifugal pump located in a sump near the canal. In carrying out the experiment the land was not provided with sufficiently high levees, so that improper flooding was obtained. The alkali was removed so unevenly from the soil as to leave it spotted. The land, however, was greatly improved. and even under such adverse circumstances fair crops were obtained that season. After the experiment was concluded the pumping was still continued, but the chain drive broke frequently, due to wear, and as a result the pump was not used for the greater part of two seasons. Only a few weeks transpired after the cessation of the pumping until the alkali began to accumulate as badly as before the reclamation commenced. There is little doubt that this tract would have been restored to its former productiveness had the drainage been maintained and the flooding continued with a proper depth of water over the surface. It is important, therefore, in order to secure a continuous drainage, other things being in satisfactory operation, that the source of power for pumping be dependable. Electric power, when available, as compared with either gasoline or steam power, is the most economical because it is the more reliable and requires the least attention, repairs, and care. This apparent failure of a reclamation scheme created unfavorable comment and acute skepticism, in the face of which this Office started its work in the same district.

THE AMOUNT OF WATER PUMPED AND THE EFFECT ON THE GROUND-WATER LEVEL.

The accompanying table giving the records of pumping plants for 1907 and 1908 shows the quantity of water pumped from each of the tile-drainage systems and gives a comparison of the height of the water table on the drainage tracts and away from the tracts:

Records of pumping plants for 1907–8.

DORE TRACT.

Date.	1907.			1908.		
	Amount pumped per 24 hours.	Average depth to water table on tract.	Average depth to water table away from tract.	Amount pumped per 24 hours.	Average depth to water table on tract.	Average depth to water away from tract.
	Gallons.	*Feet.*	*Feet.*	*Gallons.*	*Feet.*	*Feet.*
February 15		2.5	2.0	273,000		4.1
March 1		2.2	1.0	[a]417,000		3.8
March 15		1.9	1.1	[a]420,000		3.6
April 1	[a]239,000		1.1	280,000	3.2	3.2
April 15	[a]340,000		2.2	180,000	3.4	3.4
May 1	[a]239,000	3.5	2.8	160,000	3.3	1.9
May 15	152,000	3.6	3.0	155,000	3.2	2.6
June 1	[a]160,000	4.0	3.0	145,000	3.5	2.5
June 15	76,000	3.6	3.1	90,000	4.1	2.7
July 1	52,000	4.3	3.2	65,000	4.7	3.0
July 15	45,000	4.6	3.6	35,000	5.1	3.2
August 1	11,000	4.6	3.7		5.2	4.9
August 15	10,000	4.7	3.7		6.0	4.7
September 1	10,000	4.1	3.8		6.0	4.9
September 15	10,000	5.0	4.0		6.2	6.2
October 1	5,000	5.2	4.5		6.3	6.3
October 15		5.6	5.5			
November 1		[b]5.5	5.0			
November 15		5.7	5.3			
December 1		5.7	5.0			
December 15		5.1	5.0			
BAKER TRACT.						
January 1				[a]34,000	4.8	4.6
January 15				[a]30,000	4.2	4.4
February 1				30,000	4.1	4.0
February 15				36,000	3.8	3.7
March 1				43,000	3.6	3.3
March 15		2.0	1.9	[a]53,000	3.3	3.1
April 1	120,000	2.1	1.8	[a]155,000	2.9	3.1
April 15	115,000	2.3	1.8	[a]110,000	2.9	2.9
May 1	111,000	3.5	2.2	59,000	2.6	2.5
May 15	111,000	3.8	2.3	58,000	3.0	2.8
June 1	110,000	3.2	2.3	57,000	3.0	2.8
June 15	60,000	3.0	2.5	57,000	3.4	3.0
July 1	52,000	3.6	3.4	60,000	3.8	3.2
July 15	32,000	3.7	3.5	58,000	4.2	3.2
August 1	86,400	3.6	4.1	37,000	4.5	4.5
August 15	46,000	3.9	3.9	26,000	4.9	5.1
September 1	36,000	4.0	5.2	13,000	5.4	5.5
September 15	18,000	4.0	5.1	5,000	5.8	6.0
October 1	15,000	4.4	5.5	3,000	5.7	6.1
October 15	5,000	5.2	5.6			

[a] Surface flooding of land.

[b] Rain.

During the greater part of the summer of 1907 the Baker tract was surface flooded to remove alkali, this flooding being more or less intermittent and the water table rising and falling accordingly. Furthermore, the tile lines that had been laid in the early spring when the water table was high had been thrown out of alignment and were not doing full duty.

Through 1907 there was an ample supply of water in the irrigating canals for all, and the ditches carried a full supply until late in the season. In 1908 the supply of water began to run short in July, and there was very little water running in the canals toward the latter part of the month. Rains in the mountains in August again gave a supply, and irrigating was continued late in the fall. This produced considerable fluctuation in the water table, as is shown by the table.

On August 24, 1907, the water in the sump on the Dore tract was 4.7 feet from the surface. The pump was stopped until September 7, at which time the water stood 3.7 feet from the surface and was again above the top of the tile. The well records away from the drainage system indicate little or no change in the ground-water level during these two weeks. This shows that the tile drainage was holding the water table 1 foot below the average level. The greater part of the rise of water level in the sump occurred during the week following the stopping of the pump. This indicates the rapidity with which the water will rise in the soil and emphasizes again the necessity for the continuous action of any drainage system. The drainage pump on the Dore tract was shut down again about October 15, 1907, after the water table had fallen below the line of the tile. In 1908 the water reached this low level on the 1st of August, and it was not necessary to operate the pump after that time. Hardpan interfered somewhat with the drainage on this tract and small amounts of water continued to flow in the tile until late in the fall.

EXTENT OF THE INFLUENCE OF DRAINS ON THE LEVEL OF WATER TABLE IN ADJACENT LANDS.

The well records showed also the extent of the drainage produced by the tile system on the 40 acres of the Dore tract. The fall in the level of the water table referred to above was found to be distributed gradually for a distance of more than a mile in the direction of the slope and about a mile in a northerly direction, which is 45° to the water slope. This effect is shown by the readings of the test wells taken August 24 and September 7, as follows:

Extent of influence of drains.

Miles from pump.	Lowering of level.	Miles from pump.	Lowering of level.
	Feet.		*Feet.*
1	0.1	⅜	0.7
⅞	.4	¼	.8
⅝	.5	⅛	1.0
½	.6		

ANALYSIS OF DRAINAGE WATER.

Each day during the two seasons that the two drainage plants were operated a pint of water was taken from each pump discharge. From the total water thus saved from each tract for a week a sample was taken for analysis for the purpose of determining whether or not the quantity of alkali carried by the drainage water changed as the drainage progressed. The several hundred samples thus obtained varied little during the two years. The average of the analyses of water from above the hardpan was about 32 parts soluble salts per 100,000 parts of water, while water taken from an unused dug well ran about 55 parts per 100,000. Ground water occurring below the hardpan strata and not in direct contact with the accumulation of salts in the surface soil ran about 19 parts per 100,000. Since the hardpan stratum is not continuous the water above is connected at frequent intervals with that below, and as the tile systems extended under the hardpan for a part of the way, the water discharged by the drainage pump contained only 22 parts per 100,000. It is very probable that with a large drainage system whereby the entire area affected by the high-water table could be drained, the water entering the drainage system after the excess of salts is washed from the surface soil would contain a smaller amount of salts than that pumped from the small experimental tracts where the drains receive underground water from neighboring land that has not been reclaimed. While the surface of the land was being flooded the quantity of water entering the tiles increased several fold and the salts in the water ran as high as 110 parts per 100,000. This proved that the excess alkali was not merely driven into the ground but was taken into solution and carried away by the drainage system.

ANALYSES OF SOILS ON EXPERIMENT TRACTS.

The removal of the accumulated salts is dependent upon the movement of water through the soil. A certain quantity of water must come in contact with the salts to leach them out of the soil, and it is therefore a question of how rapidly the necessary water will pass through the soil rather than one of how long the land must be flooded to have the desired effect. It will take much less time to cleanse sandy soil than clay soil, because the rate of percolation is much faster in the former. It will also take less time to cleanse soil that is free from impervious subsoil, such as hardpan, than that where hardpan is present to form a stoppage to the downward percolation of water. If the drainage system is not efficient and will not remove the water as fast as it can move through the soil, the reclamation work will be retarded accordingly. If the underground water is carried out of the soil by an efficient drainage system, the passage of the water through the soil will serve to wash the alkali from the lower strata by rendering the soil more porous and enabling more of the salts to be taken into solution. The flow of water will also be accelerated beyond normal conditions and will continue to increase for some time after the system has been installed.

Throughout the entire period of experimenting with the two tracts at Fresno a quite thorough sampling of the water and the soil was carried on and analyses made of all the samples. This was done for the purpose of showing the result of each operation in the drainage and reclamation experiments and to determine what step was advisable next. The most of the analyses of the soils and water were made by W. W. Mackie, of the Bureau of Soils, United States Department of Agriculture. There were several hundred analyses, but this report will give only such of them as have direct bearing upon special points.

The Dore tract was divided into 24 rectangular checks by the vineyard roads. In March, 1907, after the tile had been laid and before the surface flooding had been done, a set of soil samples was taken. A boring was made with a 1.5-inch auger in the center of each check and a separate sample was made of each foot in depth for 4 feet. The land was then flooded for a period of five days and a new set of samples taken as before. In February and the early part of March, 1908, after the tile systems had been reconstructed, the entire 40 acres were again flooded for a period of thirty days. A third set of samples was then taken. The following summary, which gives averages of the twenty-four samples from each of the 4 feet in depth and for each of the three sets of samples, shows the extent to which the injurious salts were removed from the soil by the two floodings:

Percentage of soluble salts in soil samples.

Depth.	Before flooding, 1907.	After flooding, 1907.	After flooding, 1908.
Feet.	*Per cent.*	*Per cent.*	*Per cent.*
1	0.25	0.15	0.044
2	.25	.18	.033
3	.15	.17	.048
4	.12	.15	.042

The above table gives a fair general idea of the benefits to be derived, but does not give an absolutely just impression, because the greater portion of the tract was cleansed of alkali more thoroughly than the final figures indicate. The separate samples showed much of the soil to contain less than 0.02 per cent of salts after the final flooding, but the average was raised by a few samples taken from a part of the vineyard where hardpan lies within 2 feet of the surface and hindered the drainage action.

A composite sample of crusts taken from the surface of the Dore and Baker tracts before the experimental work was started contained 3.10 per cent of alkali, which represented an accumulation that has been going on for years. This excessive amount was on the surface, however, and did not extend through more than an inch of soil. This surface crust was readily dissolved and the surface cleansed by flooding.

One of the most important factors in the reclamation of alkali land by the flooding methods is that the excess of water used to leach the salts from the soil tends to dissipate the black alkali which is so deadly to plant life. After the land had been flooded for two or three weeks it was found that the black alkali had disappeared largely, even though a comparatively large amount of other salts was still retained by the soil. It is stated generally by authorities on the subject that 0.05 to 0.1 per cent of black alkali is fatal to plant life. Some plants will apparently do well in soil that contains a greater amount of black alkali than 0.1 per cent, but the muscats are among the more tender vines and are very susceptible to alkali, so the above results show that the quantity of alkali remaining in the soil after last flooding the Dore tract was negligible.

It is a common observation that alkali tends to rise to the surface on the high places, although practically the same amount of alkali may be scattered through the soil on the lower ground. This point was nicely illustrated on the walls of a ditch that was dug on the Dore tract for a tile line before the winter rains commenced in 1906. In cultivating the muscat vines the dirt had been thrown to the vines, leaving the surface between the rows about 5 inches below the rows. The ditch was dug obliquely across the rows of vines, making the distance 12.5 feet from center to center of the rows as the ditch ran, while the actual spacing of the rows of vines was only 10 feet. As shown in figure 8, the alkali was confined to a depth of 5 inches on the ridge and was distributed through a depth of 15 inches in the hollow between the rows. This placement of alkali was very apparent on the walls of the ditch, because the sun had struck the damp walls for a few days and the alkali appeared on the surface as definitely as if painted there.

PERCENTAGE OF OPEN SPACE IN SOILS OCCUPIED BY DRAINAGE WATER.

In making estimates for any drainage system, it is essential that the volume of water to be handled be correctly estimated in order that the proper capacity be given to the drains. One of the main factors governing the size of drains required is the quantity of water that will drain from saturated soil, and it is readily seen that this will vary with different soils. In former estimates for drainage work at Fresno the amount of water which soils could retain and release was assumed to be 30 per cent of the volume of soil. In other words, if the ground-water level were to be lowered 1 foot, the actual amount of water drained off would be 30 per cent of 1 foot. In order to determine the actual percentage of free water in Fresno soils when thoroughly saturated, a series of experiments was conducted during the summer of 1908.

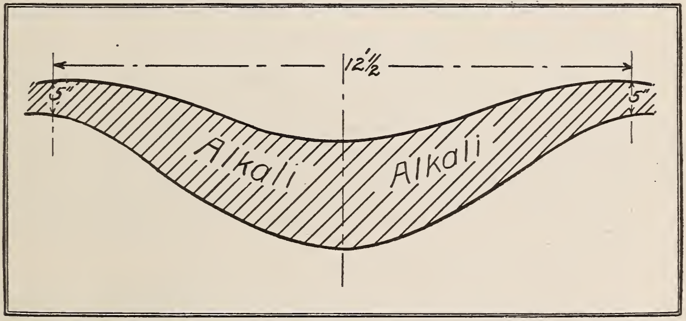


FIG. 8.—Sketch showing concentration of alkali on high ground.

Three tanks were made to hold 4, 5, and 6 feet of soil. The tanks were 18 inches in diameter, and each was set in a second tank 22 inches in diameter, the annular space between the tanks being filled with water. The tanks were buried flush with the surface of the ground and the water jacket served to maintain an even temperature throughout the soil in the inner tank, closely resembling field conditions. The soil tanks had false bottoms, thoroughly perforated and covered with 80-mesh brass screens to prevent the soil particles from going through. The tank above the false bottom was filled with soil, deposited under water without tamping and allowed to settle for two weeks, so the soil might assume a condition similar to its natural state. Water would percolate through the soil, pass through the false bottom, and be held in the bottom 6 inches of the tank. The soil tank was arranged to be lifted up out of the water jacket and weighed by means of a suspended scale attached to a derrick. The water could then be drawn from the tank by means of a valve in the bottom.

During the period of four months four experiments were conducted on different soils and under varying conditions. Accurate records were kept of the amounts of water applied, amounts lost by percolation and evaporation, weights being taken each morning, noon, and night on some of the experiments. Of the great bulk of records thus obtained only a brief summary will be given here.

The first experiment was made with a fine sandy loam taken from near the main tile line on the Baker tract. This soil closely resembles the white ash soil found in the greater part of the alkali belt at Fresno, and was chosen because the accumulation of salts had been removed by the flooding process. The soil was placed in the tanks foot for foot, as found in its natural state, and a sample of each foot taken. From these samples the air space, or percentage of voids in the dry soil, was determined by Doctor Loughridge, of the California Experiment Station, to be 30.5 per cent. After this soil had been thoroughly saturated and then thoroughly drained it was found to still contain 8 per cent of moisture near the bottom of the tank. Exposure to the sun had allowed evaporation to take an additional 2 per cent of moisture from the soil, but that would not have been liberated by drainage. Therefore, drainage equaled 22 per cent of the total volume of the soil, and the remaining 8 per cent constituted the moisture that would be retained by the soil to sustain plant life. Had the surface been cultivated the loss by evaporation would have been much less.

The above experiment was repeated with a type of soil known as Fancher Creek loam, which is a reddish-colored clay-sand loam occurring very generally to the east of Fresno. It was found to contain 40 per cent of water upon saturation, and 15 per cent of water remained in the soil after thorough drainage. This gave 25 per cent of the volume as drainage water. Judging from the nature and extent of soil of this type it is thought that a fairly accurate general average is represented by the figure of 25 per cent, which would mean removing a depth of one-fourth of a foot of water in order to lower the water level 1 foot. This would be independent of the loss by evaporation, which would vary with the field conditions and would not be a factor in the estimate for drainage. The loss by evaporation from a free-water surface was found to be as great as 0.52 inch per day during the summer.

THE CAPACITY OF A DRAINAGE SYSTEM.

Although the rise in the water table for a short period was far in excess of 0.025 foot, or 0.3 inch per day, it would not be necessary to provide a drainage system large enough to remove such an unusual amount of water as fast as the rise would occur, because the periods of unusually rapid rise are followed by periods during which the rise is less than normal. Taking the average daily rise in water table during the first four months of the year, when the need of drainage was greatest, and using this figure as a basis in computing the size of the drainage system, would insure the water table being lowered to the desired depth by the last of April or May, because the greatest amount of water to be handled occurs in February or March, and any surplus that could not be carried away then would easily be cared for afterwards. In other words, the rise in the water table might be greater than the system would discharge during a short period, but the surplus would gradually be carried away in the time of less rise. A system of this size would be in excess of the demands during some years, but it is necessary to use the season of greatest rise in the water table as a basis for estimates. Insuring a low water table by the last of May would guarantee ample feeding space for plant life during the rapid growing season, and at no time during the year would the water table be dangerous, for it would always be much lower than under existing conditions, and any unusual rise would be temporary. A sufficient capacity to prevent the rise in the early spring months would maintain a low water level during the summer months, and after the irrigation season was over the flow of water in the drainage canals would decrease until it ceased, some time between September and December.

PRACTICAL OBSERVATIONS MADE.

In constructing the tile drainage system at Fresno it was found that the cost of construction depended largely upon the condition and character of the soil. It was found also that where the soil was soft the use of tile of small diameter was impracticable, as a slight displacement in alignment would open the joints and allow the silt to enter. With larger tile this drop did not occur. Tile laid in quicksand, even when the sand is dry, is very liable to displacement, unless the tile is laid on a board base with cleats on the sides to support the tile. This displacement is liable to occur not only at the time of laying the tile, but on subsequent cleanings with a brush after the water table is above the tile.

The drainage action of tile depends upon the ground-water level with relation to the elevation of the tile—that is, if the water is much above the tile there will be a pressure to accelerate the drainage action, and with the lowering water level the flow of water will decrease. Ordinarily, if there is a considerable movement of water, the water level will not be lowered to the tile elevation, but will remain at a little distance above.

It would be impracticable to give a uniform or standard plan for the depth or location of lines of tile, as some soils drain more readily than others, but experiment has shown that the tile at a depth of less than 3.5 to 4 feet is inefficient in drainage service. In the majority of cases a depth of 4.5 to 5.5 feet is required. In order to drain well the tile should have a grade of 0.1 to 0.2 foot per 100 feet, keeping the discharge end low enough to give the upper portion as much benefit of the drainage as practicable. It has been found that a 4-inch tile should have a grade of 0.2 foot per 100; a 6-inch tile, 0.15 foot per 100; and an 8-inch tile, 0.1 foot per 100 in order to obtain the same degree of efficiency. It is seen clearly, therefore, that the amount of water to be handled determines the size of tile and the grade on which to lay it.

In general, long lines of tile should be avoided. A line of tile may become clogged when the water table is high, so that flooding may have to be discontinued before the necessary repairs can be made. If such a line is long, the clogging will cut off the drainage of a considerable amount of land; if it is short, a smaller area will be affected.

RESULTS OBTAINED IN THE DRAINAGE EXPERIMENTS AT FRESNO.

After the drainage plant had been completed in the fall of 1907 and the land had been flooded during the winter months, a marked improvement was apparent in the color and tilth of the soil. Two small checks on the Baker tract were planted to muscat vines, practically all of which lived and made a healthy growth throughout the summer. The remainder of the Baker tract was flooded continually until well into May, and was not seeded until the 1st of June. About 4 acres of land was planted to sorghum, where the hardpan was quite near the surface. This land was in poor tilth, did not retain the moisture well, and the sand was thin, yet the sorghum grew to a height of 8 or 9 feet and yielded 1.5 tons per acre. This land had returned no revenue for several years and a portion had never borne a crop.

About twelve years ago the vines on the Dore tract began to die out and, as has been previously stated, this condition of affairs spread over a large area until about one-fourth of all the vines on the 40-acre tract were dead. The growing of other crops proved futile and the strip was left barren. At the time this Office undertook the experiments on his land Mr. Dore estimated that unless the damage was checked practically the entire 40 acres would be unproductive within two or three years. After the final flooding was completed in the early part of 1908, Mr. Dore planted 1,000 muscat vines, part of them on the barren land and the remainder along the south side of the tract, where many vines were missing. At least 95 per cent of the young vines lived and made a very strong growth. This success was remarkable, because it is a well-known fact that where old vines have died there is a toxic effect produced on vines planted in the same ground. It, therefore, seems reasonable to infer that the flooding of the land had served to cleanse the soil of any poison that it might have contained as well as leaching out the alkali. Throughout the vineyard there were many stumps that had been practically without growth for two or three years. Nearly all of these put forth new growths after the land was flooded and drained. It is not to be inferred from this that vines whose root systems have been ruined by the high ground water will be restored to their former productiveness. But it does signify that if they are taken before such an advanced stage has been reached, vines that are beginning to decline may be restored by means of flooding and drainage. The producing vines put out a more healthy growth than they had had for several years previous and remained green throughout the summer, while formerly the leaves had turned yellow and withered with the first hot days of June. The vines on the drained portion of the Dore vineyard were not even affected by sunburn, which was very general in the vineyards of Fresno County during the unusually hot summer of 1908.

The raisin crop in Fresno County for 1908 was estimated to have been 20 per cent short of the normal, but the Dore tract produced as large a crop as in 1906, before the experiment started. This indicated the success of the work, for it was evident that if nothing had been done the vines in 1908 would have yielded less than one-half the 1906 crop. The health and restored vigor shown by the vines give promise of a much larger yield this year. The most favorable comment was excited by the size of the grapes and their advanced stage. The proportion of layers and clusters was unusually large for 18-year-old vines, and they were two weeks earlier than the average muscats of the country. The second crop, which was taken to the winery, contained a high percentage of sugar. These high qualities can be attributed only to the fact that drainage had enabled the soil to become warm earlier in the spring and had given the roots ampler feeding room during the growing months.

That part of the barren land not planted to muscats was seeded to alfalfa and a very heavy stand was obtained. Although three cuttings were taken from it, the alfalfa is being plowed under in order that the vacant spaces in the entire vineyard may be planted with young vines.

A DRAINAGE SYSTEM OUTLINED.

In a general way the boundaries of a drainage district for the Fresno section should include practically all of the land irrigated from the Fresno Consolidated Canal System. To trace out in detail such boundaries is not a function of this report, and it may be found upon investigation that the approximate boundaries of the land in need of drainage as herein given are erroneous. It is, however, given in order that a rough idea of the magnitude of the district may be realized. (See map, Pl. I, p. 15.)

Starting at the southwest corner of township 13, range 19, thence northeasterly to the northeast corner of township 13, range 20; thence east along the north line of township 13, range 21, to the middle of the north line of township 13, range 22; thence south to the center of township 15, range 22; thence southeast to the southeast corner of township 15, range 22; thence southwest to the middle of the west line of township 16, range 22; thence west through the middle of township 16, range 21, to the middle of the west line of township 16, range 21; thence northwest to the town of Raisin; thence northwest along the Southern Pacific Railroad to the point of intersection with the west line of township 15, range 19; thence north to the point of beginning.

The final boundaries of the district should be fixed to exclude the large bodies of land that are so high as not to be in need of drainage. It stands to reason that the small tracts of high land in the heart of the water-logged district would have to be included in the district, although they may never be in need of drainage.

It is evident from the above that approximately 200,000 acres of land surrounding Fresno should be included in one drainage district. The drainage canals would extend from near Clovis at the head of the district to the discharge point in Fresno slough, a distance of over 30 miles. Of this distance, however, the last 10 miles would be outside the district and would be traversed only by the main discharge canal. It would be useless to attempt to plan a drainage system for this area until a complete and accurate survey is made, for until such information is at hand it would be impossible to arrive at a correct conclusion as to where the canals and laterals would necessarily be placed to serve the best purpose. It is probable that three main canals would be necessary to serve the country; one running in a southwesterly direction from near Clovis past the north side of the city of Fresno and serving also the country west of Fresno, and then running south to near the town of Raisin; a second canal commencing at the eastern boundary of the district and running west through the alkali belt south of Fresno and joining the first lateral near the town of Raisin; and a third running along the south side of the district, probably through the sand swales west of Selma and joining the other two canals. From the junction of the three canals a main discharge canal should be constructed to Fresno slough. The three main laterals would not be apt to carry an equal quantity of water because the middle lateral would doubtless have to carry the storm and waste water from the city of Fresno in addition to the drainage water from a considerable territory. These canals should be constructed so deep that the surface of the water in the canal when carrying the maximum flow should be at least 7 feet below the surface of the land. Such a depth would be necessary in order that smaller laterals could have a gravity discharge into the main and still have the desired depth at all points. These smaller canals would be fed by tile systems laid in the fields, vineyards, and orchards in such a manner as to thoroughly drain all the land not influenced by the open canals. All surplus flow from the irrigation canals would be run through waste ways into the drain canals, thus doing away with one source of water-logging.

The general slope of the country around Fresno is to the southwest, the grade being 5 to 8 feet per mile in the district east of Fresno, about 5 feet per mile in the district south and southwest of Fresno, and about 4 feet per mile between the lower end of the district and Fresno slough. This slope is in excess of the grade necessary for the drainage canals and will doubtless permit of economical adjustment in the location of canals. It will permit also of a great saving in the main discharge canal from the foot of the district to Fresno slough, for since no drainage action will be required of the last 10 miles of canal the grade can be diminished and the cut gradually lessened until the minimum cost of excavation will be met in a surface canal to the slough.

As stated previously, a drainage system for this country would have to prevent a daily rise of 0.025 foot in the water table. Since the free-water capacity of this soil is 25 per cent of its volume, a drainage system should have sufficient capacity to remove 0.00625 foot per day. Assuming the area of the proposed district to be 200,000 acres, an average maximum daily flow of 1,250 acre-feet, or approximately 638 cubic feet per second, will have to be carried by the drains during the early months of the year. It would not be necessary for the system to be of a uniform size to carry this amount, because the flow would gradually increase from a zero mark at the extreme upper end of the district to the full flow at the lower end of the district.

The cost of a proper drainage system can only be guessed at until surveys are made, and even then the estimates will necessarily be comparatively rough, because of the unknown difficulties to be encountered in excavating hardpan, caving of banks in the loose soil, and the flow of quicksand lying under the hardpan. Another doubtful factor is the readiness with which rights of way can be obtained for the canals, and the cost of the same. The acreage included in the district will have much to do with the unit cost of the work. An extensive excavation will offset the first cost of the dredges and other necessary machinery, and the per acre cost of the discharge canal from the district boundary to the slough will be lower for a larger area. The cost of excavating with the small dredges used in the Modesto and Turlock districts, where the soil conditions are similar to those of the Fresno district, has been at times as low as 3.5 cents per cubic yard, and it is reasonable to suppose that the larger dredges necessary for work on canals of the size demanded for the Fresno drainage would give even a less cost.

The following estimate of the cost of construction of a drainage system for an area of 200,000 acres is quite liberal in dimensions and costs and makes allowance for the presence of hardpan and other unforeseen expense:

Approximate cost of drainage system.

Excavation of main canal: Length 60 miles, depth 8 feet, average width 30 feet, at 10 cents per cubic yard	$300,000
Main discharge canal: Length 10 miles, depth and width varying, complete	25,000
Bridges, roads, and other structures	50,000
Tile drains and small laterals for 200,000 acres	1,200,000
Organization, management, and engineering—estimated 10 per cent of total cost	200,000
Rights of way and unforeseen expenses	225,000
Total	2,000,000
Average cost per acre	10

Even should the cost reach $15 per acre, the benefits to be derived from draining the country around Fresno would be worth several times this amount.

The result of drainage throughout the world has shown it to be one of the most profitable investments which can be made to improve the land.

DRAINAGE IN THE MODESTO AND TURLOCK DISTRICTS.

GENERAL DESCRIPTION.

The Modesto and Turlock districts, located near the mouth of the Tuolumne River, in the San Joaquin Valley, were formed under the Wright Act in 1887. The Modesto district lies on the north side of the river and comprises 82,000 acres, and the Turlock district lies directly across the river to the south and comprises 176,210 acres. Both districts are supplied with water from the same source on the river, and the soil, natural conditions, and drainage requirements are quite similar. Although the districts were organized over twenty years ago, the actual use of water for irrigation was delayed by litigation in the Turlock district until 1903, and in the Modesto district until 1904. The greater part of these districts has been dry farmed for fifty years, wheat being the principal crop. Since the introduction of irrigation, however, the growing of wheat has given way largely to more profitable crops. With the exception of a strip of heavy adobe soil varying in width from 0.5 mile to 2 miles along the San Joaquin River, the soil is sandy and very productive. Hardpan is found quite generally under the entire section, at varying depths and in varying thicknesses. Borings 10 feet deep fail to show hardpan at some places, but when these points are connected they usually prove to be in sand swales, although no surface depression is apparent.

When irrigation was begun in these districts the ground-water level was 20 to 25 feet below the surface. Since that time it has risen very rapidly. In 1882 Miller McPherson sunk a well on his ranch, about 5 miles south of Modesto, near the lower end of the Turlock district but not on the lowest ground in that section, and the rise of the water table in the well is probably close to the average for the district. When the well was dug the water was 18 feet below the surface and there was no noticeable rise until irrigation was commenced. By June 12, 1906, however, the water was only 8 feet below the surface, and by June 10, 1908, it had risen to 6 feet. For the past two years the water level under the town of Turlock has been but 5 feet below the surface. In the winter and spring of 1906 the level had risen throughout the districts until ponds were standing in the swales on the lower land. By 1907 these ponds had extended until a comparatively large acreage was submerged and rendered untillable.

This rise of 15 to 20 feet within three years was the result of over-irrigation, coupled with unusually heavy rainfall during the winter. Cases are on record in these two districts where 16 acre-feet of water per acre was used during the first season of irrigation. Greater economy in the use of water is being practiced now, but it is the experience of past irrigation the world over that drainage and irrigation go hand in hand, and the best use of water in irrigation will not make drainage unnecessary in such land, but only minimize it. The damage is not confined alone to the submerged land, but extends to much land in both districts, where the water is so close to the surface that it injures the roots of trees and vines or renders cultivation impossible.

In August, 1906, this Office began investigations in the Turlock district to determine the fluctuation of the ground-water plane. Nineteen test wells were sunk in the water-logged district southwest of Turlock. The depth to water in each of these wells has been measured regularly once a week and the fluctuations of the ground water recorded. The following table shows the average depth to water on the 1st and 15th of each month in each set of wells.

Average depth to water from land surface.

Date.	Ceres.			Turlock.		
	1906.	1907.	1908.	1906.	1907.	1908.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
January 1	....	7.0	6.2	....	7.5	7.9
January 15	....	5.7	5.8	....	6.1	7.9
February 1	....	4.0	5.3	....	5.6	7.4
February 15	....	2.4	5.0	....	5.5	7.0
March 1	....	3.0	5.1	....	5.4	6.7
March 15	....	2.4	5.0	....	4.9	6.7
April 1	....	3.0	5.1	....	3.8	6.7
April 15	....	3.4	5.1	....	4.8	6.5
May 1	....	4.0	5.1	....	4.8	5 0
May 15	....	4.1	5.2	....	4.9	5.0
June 1	....	4.3	5.4	....	5.3	4.3
June 15	....	4.4	5.4	....	5.8	4.2
July 1	....	4.6	5.5	....	6.4	4.3
July 15	....	5.1	5.7	....	6.7	4.7
August 1	....	5.9	6.0	....	7.1	5.4
August 15	....	6.7	6.3	....	7.3	6.1
September 1	....	7.3	6.4	....	7.3	6.9
September 15	....	7.4	6.6	....	7.4	7.7
October 1	7.8	7.4	6.8	8.3	7.3	7.4
October 15	7.8	7.3	6.9	8.4	7.6	7.6
November 1	7.9	7.1	6.8	8 5	8.0	7.8
November 15	7.9	6.7	....	8.5	8.2	....
December 1	8.0	6.6	....	8.6	8.2	....
December 15	7.6	6.3	....	8.0	8.0	....

The difference in readings for the early spring months of 1907 and 1908 is due largely to the difference in rainfall, the precipitation in 1907 being unusually heavy and in 1908 below the average. No drainage has been provided for the district surrounding the Turlock wells, and it will be noted that despite the greater depth to water during the first five months of 1908, as compared with the record of 1907, the water was 1 to 2 feet nearer the surface of the land in the summer of 1908. The Ceres wells are, however, in the section through which the drainage canal, commenced in September, 1907, by the Turlock district, is being dredged, and the records for these wells show that at no time during the summer of 1908 was the water table closer than 5 feet to the surface, thus allowing ample feeding space for plant life. This shows that the drainage canal not only lowered the water to a desirable depth from the surface, but also prevented the rise of 1 or 2 feet, which it is reasonable to suppose would have occurred, judging from the Turlock well records.

During the spring of 1907 A. Griffin, engineer and superintendent of the Modesto irrigation district, placed about fifteen gauge rods in the water-logged area, distributing them from near Modesto to the lower lands along the San Joaquin River. These rods were so placed in the surface water that the 4-foot mark was at the surface of the pond water and readings were taken on all of them at various times throughout the summer. The readings on September 12 varied from 0.03 foot to 3.95 feet, showing that the water during the summer had fallen about 4 feet at some points, while at other places it remained nearly stationary. The water level had been affected by seepage from ditches and from irrigation of lands surrounding the ponds in a few cases, but in general the greatest fall in ground water was found at the lower side of the district, near the river, while the least fall was near Modesto. This fall was quite gradual, and a profile of the water level would be quite regular.

The above results show that the drainage had gradually decreased in effect from the lower lands to the heart of the irrigation district. This smaller fall, where irrigation was heaviest, may be due to the fact that the surplus irrigation water, applied both here and higher up in the district, percolated into the soil more rapidly than the fall of the country would drain it away.

Irrigation being new to the people in these districts and drainage being forced upon them so suddenly, they did not realize at first the importance of drainage, and the customary differences of opinion arose as to the advisability of starting a costly drainage system. Even greater argument arose as to the means to be employed to relieve the water-logged area and prevent the encroachment of water upon other land. Some advised pumping from the low areas and from wells and discharging the water into the irrigation ditches, while others favored open-ditch drains. The landowners whose lands were so high that they did not require drainage were opposed to expending money for drainage in any form, since the funds for drainage work would be obtained by taxing all the land in the district, be it high or low. They did not consider the fact that the conditions which made drainage necessary were in a great measure produced by irrigation on the higher lands. This opposition to drainage weakened, however, as the gradually increasing height of the ground water water-logged higher land. In August, 1907, a proposal to vote $20,000 in bonds for draining was carried in the Modesto district by a good majority. Drainage work in the Turlock district is being paid for with general-improvement bonds of the irrigation district, which were voted before drainage was necessary, but are available for such work.

PUMPING EXPERIMENTS.

In the early part of May, 1907, the directors of the Turlock district, after much agitation, ordered an experimental pumping plant to be installed. A 10-inch well was drilled about 3 miles west of Turlock, in a low place where water had stood on the surface during the entire spring. It was sunk to the first water-bearing stratum of gravel about 23 feet below the surface and the casing was thoroughly perforated. A 6-inch horizontal centrifugal pump was set in a pit 1 foot below the surface of the ground and belt connected with a 26-horsepower portable, standard type, double-cylinder gas engine. An 8-inch suction was used, connected to the pump by elbow, and the water discharged through a 6-inch pipe into an open box flume 5 feet above the pump and leading to an irrigation lateral.

This Office had test wells put down about 1,000 feet apart in lines extending about a mile in each direction from the pump. These wells were about 4 inches in diameter and cased with light galvanized iron to prevent the sand from caving in. Observations were made as to the level of the ground water and recorded by this Office twice each week during the four weeks the pump was operated.

The pump when operated discharged about 1,000 gallons per minute, but owing to numerous breakdowns of the engine it was operated only a small part of the time and no lowering of the level of the ground water was apparent in the test wells. The greater part of the water pumped came from the stratum of gravel. The water in this stratum is doubtless connected with the surface portion of the underground water, but the connection is so indirect that it is doubtful if even the removal of a large body of water from the gravel stratum would affect the surface water.

The rapid rise of the ground water in the Modesto district caused the landowners and board of directors to begin to consider the most feasible methods of draining the affected land. Two methods were proposed, pumping and open-ditch drainage. The higher cost of construction and the cost of maintenance of open ditches led to an investigation of the practicability of using pumps in wells. It is clearly evident, in this district at least, that the surface water is connected with the body of water lying below the stratum of hardpan. Consequently the opinion grew that pumping from the large body underlying the hardpan would lower the surface-water plane, since a greater flow could be obtained at a depth than from shallow wells that must get their supply from the surface soil alone. With this idea, A. Griffin, the superintendent, was given authority in June, 1907, to purchase a pumping plant and install it for experimental purposes. A water-logged section about 6 miles northwest of Modesto was chosen for a site, and a 30-horsepower gas engine, belt-connected to a No. 10 horizontal centrifugal pump, was installed.

Working on the idea that the supply of water will be dependent upon the area of the supply basin, Mr. Griffin figured to improve upon a drilled well. A hole about 3.5 feet in diameter was dug through the hardpan, which was only 5 feet from the surface, into a sand and gravel bed. The pump was started, a supply of water being run into the hole from the irrigation ditch. The mixture of sand and water was discharged from the pump into a settling basin, where the sand settled while the water ran back into the hole to maintain suction. In this way sand was pumped out until a great cavity was formed about 10 feet deep and shaped like an inverted truncated cone, when the hardpan gave way under the weight of the pump and this cavity was open to the surface. Two timbers 24 by 30 inches and 40 feet long were placed horizontally on the surface to support the pump, and the sand and pieces of hardpan were pumped out until the hole was about 18 feet deep, the suction being lengthened 2 feet at a time. At that depth a 4-foot deposit of red clay was encountered which the suction would not remove; so a hole was drilled through it and the suction lowered to a stratum of sand beneath. Previous to this, however, a casing had been put in the hole to keep pieces of hardpan from getting into the suction and delaying the work. The suction was then 23 feet and the water was not so great as hoped for. Although the capacity of the pump was about 3,000 gallons per minute, the best supply obtained previous to piercing the clay was only about one-third capacity, or 1,000 gallons per minute, due chiefly to the fact that the casing cut off the surface supply in a great measure. The many changes demanded by this system caused the pump to be idle a considerable portion of the time and the good derived could not be easily ascertained, as it was not indicated by the test-well readings.

OPEN-DITCH DRAINAGE EXPERIMENTS.

Both experiments described above were conducted in such a way as to prove nothing and rendered slight service in settling the question of the advisability of pumping for lowering the water table. It is worthy of note, also, that even at this advanced stage there were many who opposed spending money for drainage, because as the summer progressed the water table receded, as it does every year, only to rise even higher the succeeding year. However, as a result of the poor showing of the pumps the open-ditch method of drains was agreed upon and the first work was commenced in the Turlock district in August.

EXPERIMENT IN THE TURLOCK DISTRICT.

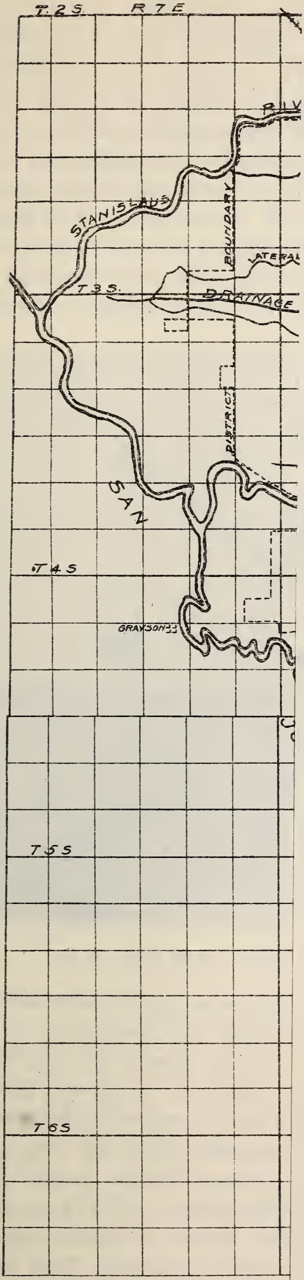
This consisted of a shallow ditch dug with teams and scrapers to drain a chain of lakes. It commenced about 7 miles southwest of Ceres at the McKabe Lake, ran about 2.5 miles in a southwesterly direction, and emptied into a slough which discharges into the San Joaquin River (Pl. II). The grade of the ditch was about 3 feet to the mile and was started at an elevation that would permit of the first pond being drained. The soil is heavy adobe and the ditch was dug as narrow as possible with the scrapers, the average cut being 3 to 4 feet. This drain, however, runs through a natural depression connecting the lakes and the general elevation of the land is about 8 feet above the bottom of the drain. This ditch is considered to be a halfway experimental expedient, but for many reasons it seems that it should have been dug at least 3 feet below the surface of the ponds in order to properly relieve the water-logged land. Excavation cost about 8 cents per cubic yard.

About a half mile below the head of the ditch there was a natural dike of hard gray hardpan, which rose about 6 feet above the bottoms of the two lakes which it separated and necessitated blasting. This crest, which was about 40 feet thick where the ditch was excavated, had such a slope to its sides that it came to a sharp edge at the top. Blanket formations of hardpan were encountered at the surface at several points along the ditch and, though not so high as the first one, they occurred in a wavelike form. The first crest of hardpan was not cut through and it is not known how thick it is. It is possible that these crests, which occur at right angles to the slope of the country, are in a great measure responsible for the backing up of the ground water and that they prevent the more ready and rapid drainage of the higher lands. This idea is supported by the fact that though the two ponds which this crest separated were only 200 feet apart the surface of the water in one was 1.5 feet above the other. There is a fall of 4 to 5 feet per mile throughout the two districts and the water table has a slope similar to that of the surface of the land.

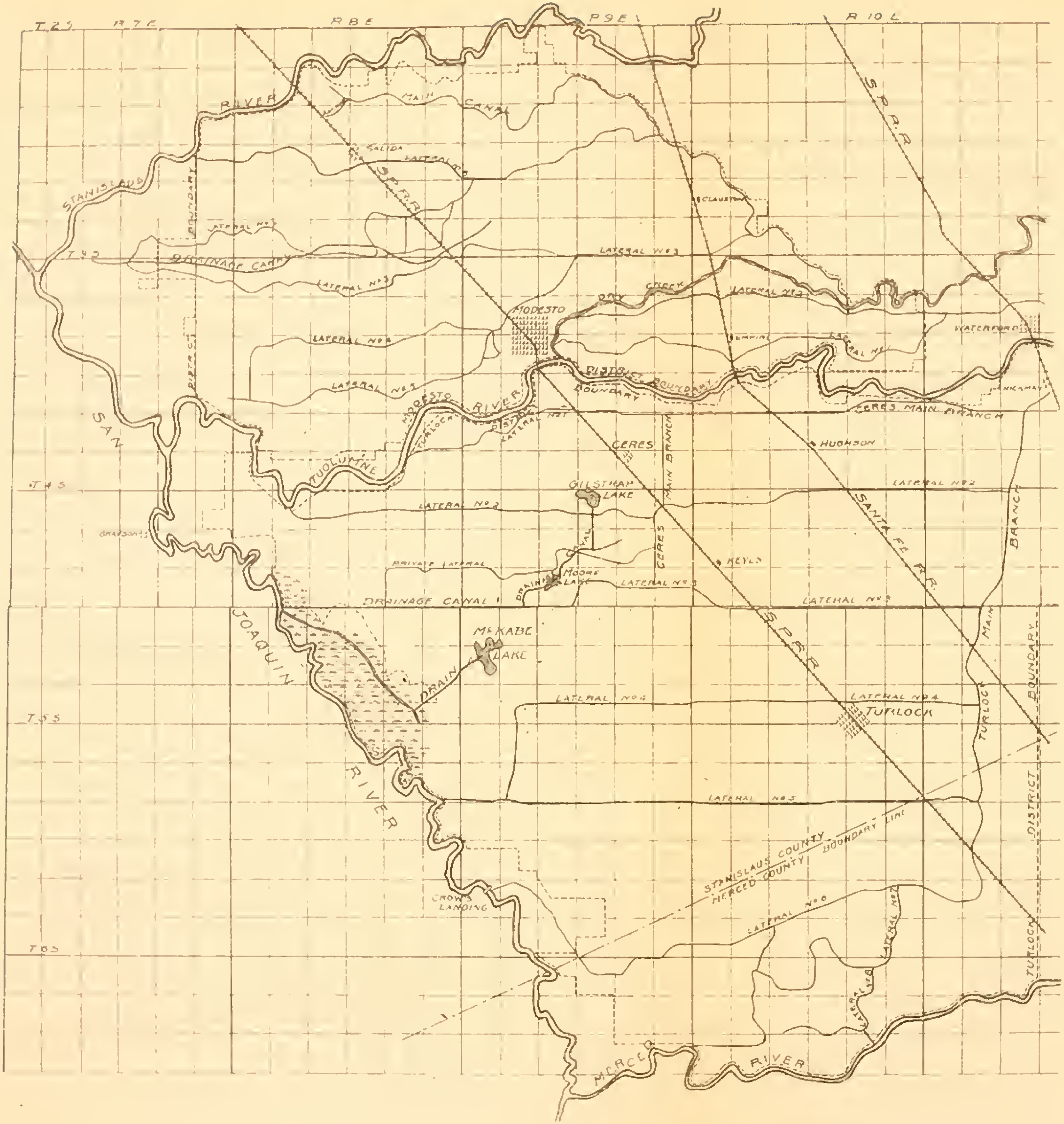
The land away from the river bottoms is so sandy that water percolates through it quite rapidly, but the soil at the foot of the slope near the river is a compact adobe and water passes through it with difficulty. This fact is also held to be responsible for much of the water-logging of high lands, since the water can not get away rapidly enough at the lower end. It is believed, therefore, that if this crest of hardpan and strip of heavy soil were punctured in several places by digging ditches through them the sandy soil on the higher land would be drained more freely.

Owing to the still considerable opposition to drainage, the work in the Turlock district is not being done on a permanent basis. The

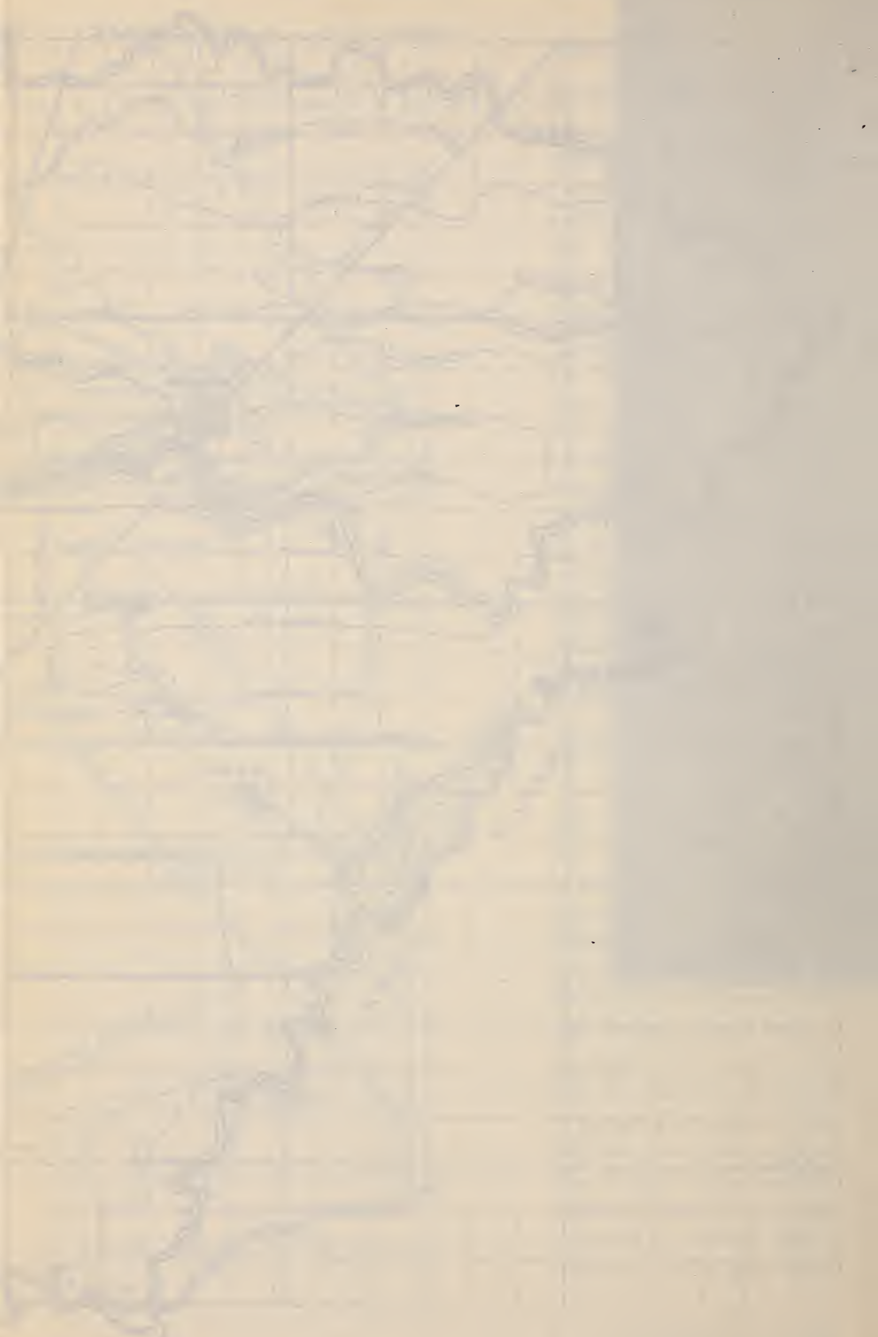
U. S. Dept. of Agr.,Bul. 217. Office of Ex



MAP OF MODEST



Map of Modesto and Turlock Irrigation Districts, Showing Location of Irrigation Canals and Drains.



ditches are being dug narrow and shallow, but if found to be insufficient for the discharge of the water they will be enlarged and extended in the future. The first important move in drainage in this district was made in June, 1907, when a dry-land or skid dredge was ordered, costing about $5,000. This was built in Stockton, Cal., and was delivered in September. It is of the type which moves in the axial line of the canal to be dug and recedes from the breast of the canal as it is excavated. It differs from the side line dredge in that its boom motion is produced by a turntable. The dredge machinery is mounted on a skid platform 18 by 30 feet, which rests on several movable wooden rollers run on planks placed on the ground (fig. 9).

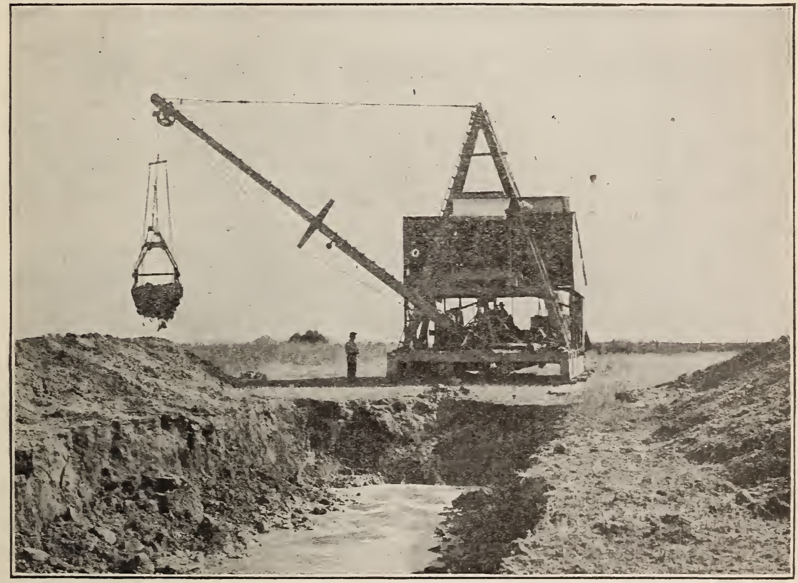


FIG. 9.—Skid dredge operating on Modesto and Turlock drainage canals.

As the canal is excavated the dredge is moved or fleeted 3 to 5 feet at a time by means of a steel cable anchored to a "dead man" several hundred feet ahead of the dredge, and wound on a drum, which is power-driven by a worm gear from the engine. The tower or A frame which supports the 40-foot boom is 20 feet high. This boom supports the cable sheaves for the bucket and inclines about 45°, but has no vertical motion, although it may be swung about 180° horizontally by a cable-propelled turntable located at the front of the dredge under the tower. The bucket is a 1 cubic yard capacity clamshell type, weighing about 2,800 pounds. The machine is controlled by means of three levers and two foot brakes, mounted on a platform on the A frame. Power is furnished by a 25-horsepower single-cylinder gasoline engine, which drives a series of combination gear and friction brake drums controlling the motion of the excavating bucket.

This dredge was set up on the south side of Moore Lake about 6 miles south of the town of Modesto. This laks was formed by the ground water rising in low land at this point and is the head of a series of small lakes or ponds running southwest toward the San Joaquin River. As will be seen by the map (p. 52) the Moore and McCabe lakes, with the smaller ones, lie in line, but a canal connecting Moore Lake with McKabe Lake and the ditch already dug would be impracticable, as there is a ridge of higher land between lateral 3 and McKabe Lake that would necessitate too great a cut being made. For this reason, and because a greater territory could be drained by the two canals, the canal from Moore Lake was run to lateral No. 3 and from that point the lateral was dredged out to form a drainage canal. For the present the drainage waters will be discharged on the bottom lands, but if in the future the canal is dredged deeper the excavation will be continued to the river and the ditch will discharge directly into the river.

Work on this canal was started at the upper end, contrary to the usual manner of digging canals for drainage purposes. When boat dredges are used the canal is started at the head in order to have a channel filled with water for the dredge to float in. With a dry-land machine this is not necessary and it is customary to start at the lower end and work up, thus allowing the ditch to drain itself. Another advantage of this method is that if work is discontinued before the entire length is completed the portion excavated forms a perfect drainage canal for that distance. The canal is about 20 feet wide on the surface and the banks are left as steep as possible, the idea being to make the ditch as narrow as possible in its final shape and still maintain a depth of about 3.5 feet below the present water line. This will necessitate a total depth of 5.5 to 6 feet below the surface of the land traversed by the ditch, which is lower than the general level of the land. All the material excavated from the canal is dumped on one side of the canal in order that the dredge might come back on the other side without the expense of leveling the land if it became necessary to make the canal larger or to clean it in the future. A 6-foot berm was left with the expectation that the banks will cave to an angle of repose in such sandy soil so as to leave the bottom of the canal about 6 feet wide. When the canal was extended into higher land it became necessary to increase the depth and to make spoil banks on both sides.

EXPERIMENT IN THE MODESTO DISTRICT.

The slope of the land in the Modesto district is about 5 feet to the mile from east and west and the irrigation laterals follow the greatest slope. Throughout the district there are well-defined swales which are more or less continuous and are divided occasionally into ponds by sand blows. Borings with a soil auger show these depressions or swales to be 10 to 15 feet deep and quite free from hardpan. Below this deposit of coarse sand and gravel there is a layer of clay about 3 feet deep and immediately below this clay a stratum of very fine quicksand. These swales are easily traced from surface indications and it appears that they are old channels of the Tuolumne River. The problem of drainage in this district is well defined, for canals dredged to connect the ponds and make a continuous drainage ditch of the swales will be not only more easily constructed than they would be in higher lands, but will be located where the natural drainage facilities are the best. It is quite probable that similar conditions of old river channels exist on the Turlock side, but for the most part they have been filled with sand carried by the winds.

A careful survey of the drainage canal, as shown by the accompanying map (Pl. II, p. 52, was made during the summer of 1907. In September of that year the Modesto district purchased a dredge of the same type and capacity as that used by the Turlock district, which was put in operation about February 1, 1908. The drainage ditch runs in a westerly direction between irrigation laterals Nos. 3 and 7, following one of these sand swales quite closely. It crosses lateral No. 7 twice and heavy fills were made at these points in laying out the lateral. In order to expedite the work scraper teams were put to work on the lower end of the canal where the cut was slight and the soil was very heavy, for under such conditions dirt can be excavated with teams about as cheaply as with a dredge. After 1.5 miles of the canal had been dug with teams the cut became so deep that the horses bogged in the bottom and it was necessary to start the dredge at that point.

The canal discharges the water upon the flats of the San Joaquin River near the point where the waste water from lateral No. 7 spreads over the flats. The surface soil of the flats is a heavy adobe about 2 feet thick and underlain with whitish clay varying from 5 to 75 feet in thickness. The land is too wet for cultivation during the greater part of the year and can be used only for pasturage. The canal extends into this belt for about 2 miles.

The farmers at the end of lateral No. 7 have constructed a levee to hold the waste irrigation water with which to flood their lands. From this point the canal takes a gradual grade which, with the rise of the surface, gives a 4-foot cut at a point 1.5 miles east of the discharge end. From there on the depth is practically the full cut, which is about 6 feet. In places the cut varies to meet the irregularities of the surface. The canal is located in low land and its bottom averages nearly 10 feet below the general land level. This placing of the canal in the low land not only permitted a greater depth of canal with a minimum amount of excavation, but secures the maximum drainage effect by utilizing the natural drainage courses.

In order to determine the average cost of moving dirt with the type of dredge used by the two districts, data were kept on the supplies, repairs, wages of crew, and other expenses connected with excavating the Modesto drainage canal across the ranch owned by C. A. High. This was considered a fair average of conditions, and would represent a fair average unit cost of excavating.

Data as to cost of dredging on Modesto drainage ditch for one month.

Wages of crew for one month:		
Foreman	$95.00	
Assistant foreman	85.00	
Swamper	50.00	
Swamper, one-half month	25.00	
Man and team (half time)	50.00	
		$305.00
Supplies:		
400 feet ⅜-inch hoisting cable	50.40	
6½ gallons gasoline	1.60	
3 gallons lubricating oil	3.75	
5 pounds Hecla compound	1.25	
595 gallons distillate, at 7.5 cents per gallon	44.62	
1 cylinder cup	3.00	
Rollers	21.00	
Large intermediate gear	14.00	
172 pounds dynamite, at 16 cents per pound	27.52	
1,000 feet fuse	7.50	
2 boxes caps	1.60	
Depreciation of dredge ($5.000)	40.00	
		216.24
Total		521.24

Total cost of excavation	$521.24
Total cubic yards excavated	14,941
Cost per cubic yard excavated	$0.035
Operation cost per hour (based on 255 hours)	$2.05
Operation cost per hour (based on 200 hours)	$2.61
Cubic yards excavated per hour (based on 255 hours)	58.6
Cubic yards excavated per hour (based on 200 hours)	74.7

An actual cost of 3.5 cents per cubic yard of excavation is very good under ordinary conditions, and especially low considering the fact that this cost includes excavation of hardpan and that the proportion of time lost in making repairs was abnormal. The customary contract price for moving surface dirt with teams in this district has been about 8 cents per cubic yard where no hardpan is encountered, and the excavation of hardpan has cost as high as 50 cents per cubic yard. Comparing this with the above figure of 3.5 cents gives a decided advantage in favor of dredge operation where practicable.

The volume of soil handled per hour speaks well also for the type of dredge used. An average of 747 cubic yards per ten-hour shift for twenty days is a good record for a machine with so low a first cost and such low operating costs.

With so small a part of the canal excavated and that part having been completed for such a short time, it is not possible to determine at this time the extent of its effect. Surface indications show that it is draining the land. When about 3.5 miles had been excavated measurements showed the discharge to be 3.59 cubic feet per second. Further measurements taken 2 miles above the discharge end of the canal gave 2.6 cubic feet per second. This shows that the greater part of the water was coming from the part of the canal extending into the district where the heaviest irrigation has been practiced.

SUMMARY.

These canals are merely the first steps toward drainage systems that in time will assume far greater magnitude. For this reason they should be well constructed, as the expense of remodeling old works is far greater than that of first-hand construction. The canals being dug at present are located in the worst water-logged areas and therefore will be the main arteries of the completed systems. New canals, extensions, and branch lines will have to be built in the future to care for localities not only where there are ponds of standing water, but where the water plane has come so near the surface that the roots of trees and vines are immersed constantly. This lowering of the water level will also prevent the soil from becoming worthless owing to the accumulation of alkali on the surface. The general belief that this country is free from alkali is in part incorrect, for there are numerous local cases throughout the two districts where alkali, both black and white, is to be seen in abundance on the surface of the present water-logged lands. If the water is allowed to remain near the surface, capillarity and evaporation will increase the surface alkali and ruin much of the fertile and productive lowland. The greater part of the land in this area is of such a nature and the surface conditions are such as to make it quite improbable that alkali would ever interfere with its value. But the sweeping statement that there is no alkali in the Modesto and Turlock irrigation districts is erroneous and misleading.

As before stated, in laying out drainage canals it is very advantageous to follow the lines of old stream channels or other natural waterways that are now obliterated by sand blows, or at least only apparent in places on the surface. These old waterways are clearly defined in the Modesto district, but on the Turlock side of the Tuolumne River they have been filled with sand, and it would be necessary to make a series of test borings in order to find even the channels, which are marked in places by ponds. Chance borings over many parts of the district have led to the theory that there are a still greater number of old channels that are completely filled. For this reason it might be economy to make a thorough, systematic set of borings, at least over the lower part of the district, in order to make a map of the conditions to be encountered in the first few feet of soil. This should be accompanied by a good topographical survey, showing the contour lines throughout the district, in order to facilitate the work of the farmer and the engineer in planning irrigation and drainage systems. The Modesto district has a good contour map. The expense of compiling this map was quite large, but it is invaluable and therefore a good investment. The entire expense of having a party of able and accurate men make borings and define channels might be saved in the location of one small canal, for it would not take a great distance of improperly located canal, not giving the maximum drainage effect, to waste an amount of money sufficient to insure the best results in such work.

The theory that much of the water-logging in the higher land is due to the heavy soils at the lower elevations along the bottom lands of the San Joaquin and the crests or ridges of hardpan running through them may be well founded, and the results attained in relieving this condition by means of the ditches cut through these formations should be watched closely.

O